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| Topic: | **Reservoir Committee Agenda Item 1-2** **2018 Jan 19** |
| Subject: | **Special Presentation by Jeffery Mount: Accounting for Environmental Water & Managing Freshwater Ecosystems** |

## Requested Action:

No action requested. Special presentation to the Reservoir Committee from Jeffery Mount.

## Detailed Description/Background:

Special presentation from Jeffery Mount; Senior Fellow at the Public Policy Institute of California and Professor Emeritus at the Department of Earth and Planetary Sciences, UC Davis regarding accounting for environmental water.

## Prior Reservoir Committee Action:

None.

## Fiscal Impact/Funding Source:

None.

## Staff Contact:

Rob Thomson

## Attachments:

Attachment A – Accounting for Environmental Water

Attachment B – Managing Freshwater Ecosystems

PPIC PUBLIC POLICY INSTITUTE OF CALIFORNIA

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# A New Approach to Accounting for Environmental Water

## Insights from the Sacramento–San Joaquin Delta

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Cover photo courtesy of Carson Jeffres.

## SUMMARY

## CONTENTS



Technical appendices to this paper are available on the PPIC website.


How water is apportioned to California's cities, farms, and the environment can lead to conflict and competition in times of drought. Allocation of water to the environment in particular is poorly accounted for and poorly understood—shortcomings that can affect water policy, decision making, and public perception. This report reviews the state's long-standing methods for defining and accounting for environmental water and proposes reforms to improve the timeliness, transparency, and detail in the accounting of environmental water allocation.

Foremost among our recommendations is that the state adopt a new approach to environmental water accounting. In particular, we propose separating out two portions of environmental water that are currently lumped together: "ecosystem water" used exclusively to support fish and wildlife, and "system water" primarily managed to meet the needs of agricultural and urban water users, such as preventing high salinity levels.

The state should also more consistently track water that exceeds water demands and diversion capacity ("uncaptured water"), which can provide significant benefits for water users and ecosystems.

We illustrate this approach using the Sacramento–San Joaquin Delta as a test case. The Delta is California's most important water supply hub, and allocation of water to the environment has been mired in controversy. We find that water for the ecosystem has been growing since the mid-1990s because of regulatory changes to improve conditions for endangered fish, and trade-offs have been rising between ecosystem uses and exports. But contrary to popular understanding, a large and growing volume of environmental water is actually "system water" required to protect the quality of diversions by farms and cities that rely on exports from the Delta or use water locally. Although this water also provides ecosystem benefits, it would be required even if there were no ecosystem management objectives in the region.

This example is a model for improving the transparency of environmental water accounting in other watersheds as well. Although details will vary among watersheds, this approach can be used to achieve more efficient and effective use of California's water resources, and reduce conflict over water used for environmental purposes.

# Introduction

California's allocation of water to the environment is poorly accounted for and poorly understood (Escriva-Bou et al. 2016). Problems include a lack of current, transparent, and adequately detailed information to inform policy and management decisions, regulatory review, and public debate. These information gaps heighten controversy and conflict over environmental water use, and discourage efforts to achieve the best outcomes for the economy and the environment with the state's limited water resources.

In this report, we propose a new approach to accounting for environmental water, using the example of the Sacramento–San Joaquin Delta—a hub for water exports to large parts of the state. For several decades this region has been at the center of some of California's greatest controversies over environmental water allocation (Hanak et al. 2011). During the latest drought, when water flowing into the Delta was especially low, conflicts over the apportionment of Delta water between exports and environmental uses ran especially high.

In the following pages, we review how the California Department of Water Resources (DWR) assigns water to the environment in the official state water accounts developed as part of its California Water Plan periodic updates. We then explain our recommendation to make environmental water accounting more timely, transparent, and detailed, using categories that more accurately reflect the different uses of water.

In particular, we propose separating out two portions of environmental water that are currently lumped together: "ecosystem water" used exclusively to support fish and wildlife, and "system water" primarily managed to meet the needs of agricultural and urban water users, such as prevention of high salinity levels. We also highlight the value of tracking "uncaptured water"—river water in excess of the total volume diverted by water users or kept instream for system and ecosystem purposes. Although these different categories of flows can provide multiple, overlapping benefits, we show why it is useful to distinguish among them in water accounts.

To illustrate our approach, we analyze the apportionment of inflows to the Sacramento–San Joaquin Delta for 1980–2016. We find that a large and growing volume of environmental water is actually system water—required to protect the quality of diversions by Delta exporters and in-Delta water users. Although this water also provides ecosystem benefits, it would be required even if there were no ecosystem management objectives in this region.

We also find that water assigned to the ecosystem has been increasing because of regulatory changes since the mid-1990s. Ecosystem water is most likely to present a direct trade-off with water exports during dry years, when there are fewer uncaptured flows. However, the increased use of export pumping limits for fish protection since the late 2000s has also increased the likelihood of trade-offs in normal and wet years.

We conclude with some reflections on the importance of improving environmental water accounting in the Delta and other watersheds to foster more productive discussions among stakeholders, and more efficient and effective water management.

The Delta analysis relies upon water flow and quality data from multiple sources, as well modeling to estimate the volume of water needed to meet salinity standards. Technical Appendix A summarizes the evolution of environmental water regulations included in the analysis, and Technical Appendix B summarizes methods, assumptions, and uncertainties—and describes the results in greater detail. All data are contained in *PPIC Delta Water Accounting*.

The environmental accounting approach outlined here informs a companion report, *Managing California's Freshwater Ecosystems: Lessons from the 2012–16 Drought* (Mount et al. 2017). It outlines a suite of strategies—including better accounting, planning and preparation, and water allocation methods—that can help California protect and support its freshwater ecosystems more effectively during future droughts, while reducing conflict and providing more certainty to other water users.

## Environmental Water Use in Context

The California Department of Water Resources (DWR) accounts for various uses of water in the state. It reports these results in the *California Water Plan Update* (Bulletin 160), issued approximately every five years. These water balances track both water sources and applied and net water use for the environment, farms, non-farm businesses, and homes. Applied water use is the gross volume of water put to a particular use. Net water use is determined by deducting the portion of applied water that remains in or returns to rivers, streams, or aquifers, where it becomes available for reuse.

Before the 1998 update, DWR only accounted for agricultural, municipal, and industrial uses of water. Then as dedication of water to support environmental needs grew, DWR began tracking that use as well. The 2005 update was the first to include estimates of actual, rather than modeled, water use.[1]

The most recent update of Bulletin 160 was issued in 2013 (Department of Water Resources 2013). It includes actual water use estimates from 1998 to 2010. Estimated environmental water use over this 13-year period was roughly 50 percent of the statewide total applied water use. Agriculture accounted for 40 percent and the municipal and industrial sector for the remaining 10 percent. Figure 1 shows how these shares vary across the state, and between wet and dry years.

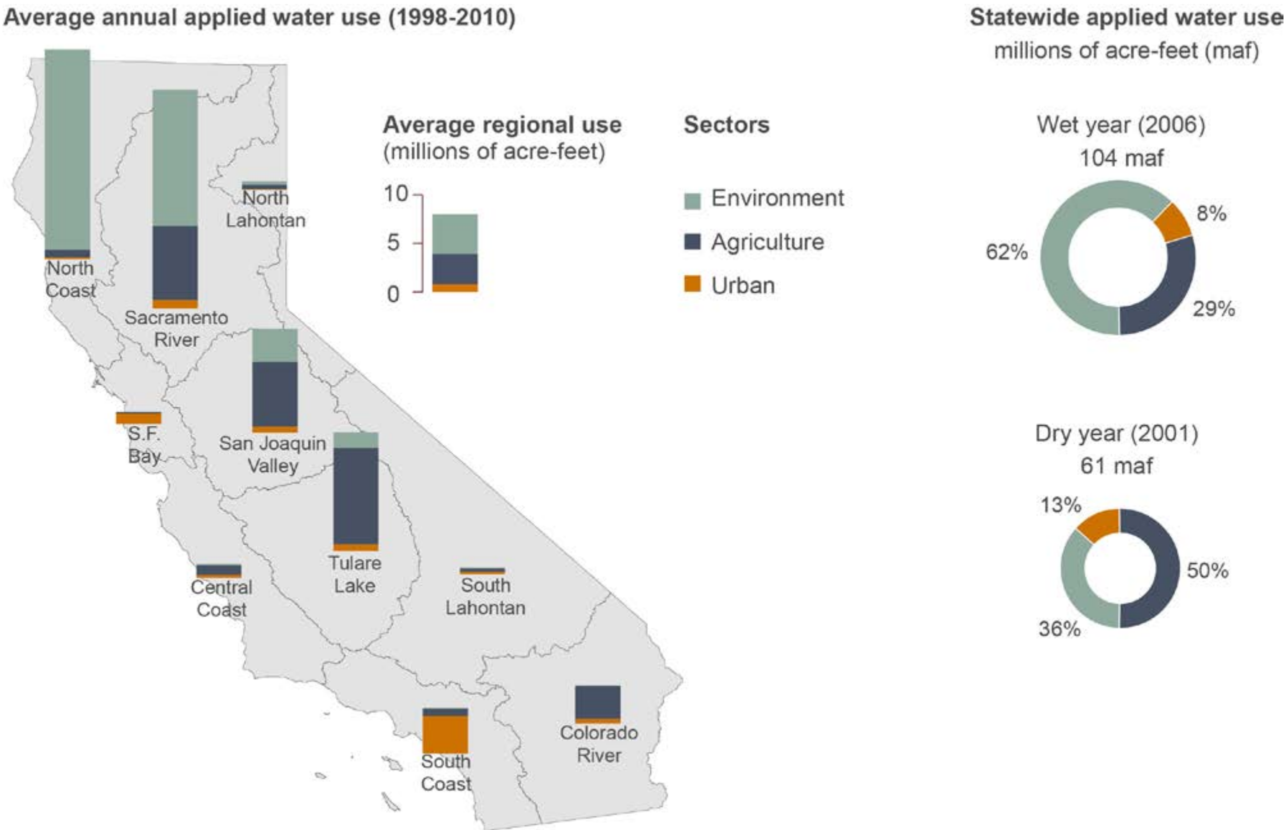
DWR divides environmental water use into four categories:

- **Federal and state "wild and scenic" rivers** (63% of the total): Water flowing on rivers or stretches of rivers protected by federal or state laws from new dams and other projects that would alter the river's free flow.[2]
- **Required Delta outflows** (16%): Water required to flow out of the Delta to protect water quality and flows for fish and for agricultural and urban diverters.
- **Instream flows** (17%): Water required in other river stretches and watersheds to protect fish and wildlife (e.g., cold water and pulse flows for salmon).
- **Managed wetlands** (4%): Water delivered to federal, state, and local wildlife refuges and private duck clubs.

[1] In prior years, the estimates were for "normalized" use—the assumed use under normal rather than wet or dry hydrologic conditions.
[2] In some cases, these designations occurred after some dams were constructed, or are confined to stretches of rivers upstream of dams—the case for upstream stretches of some rivers in the Central Valley.

**FIGURE 1**

Environmental water use varies dramatically across regions and between wet and dry years




SOURCE: Department of Water Resources (2013). California Water Plan Update (Bulletin 160-13).

NOTES: The figure shows applied water use. The statewide average for 1998-2010 was 79.8 million acre-feet (maf). Environment (40.5 maf average) includes water for "wild and scenic" rivers, required Delta outflow, instream flows, and managed wetlands. Urban (8.3 maf) includes residential, commercial, and industrial uses, and large landscapes. Agriculture (31 maf) includes water for crop production. Net water use—i.e., the volume consumed by people or plants, embodied in manufactured goods, evaporated, or discharged to saline waters—is lower. The figure excludes water used to actively recharge groundwater basins (3% for urban and 1% for agriculture on average), conveyance losses (2% for urban and 7% for agriculture), and water used for energy production (less than 2% of urban use).

In public debates, the 50 percent share for the environment is sometimes used to illustrate how much water environmental regulations cost other water users. But this statistic is misleading for two reasons. First, it does not distinguish among types of environmental water use, some of which do not conflict with other water uses. In particular, the largest share of environmental water flows in wild and scenic rivers. These rivers are mostly located in the sparsely populated North Coast, where there are no alternative uses and little controversy exists over the rivers' protected status.

Second, the averages mask how dramatically the volume and share of environmental water change from year to year depending on the amount of runoff. Environmental water reaches a peak in wet years when it has limited effect on other uses. And it reaches a minimum during dry years when a greater share of water goes to agricultural and urban uses. Most of this variation comes from large fluctuations in wild and scenic river flows. But other categories of environmental water also vary considerably with hydrology. This is because environmental water uses generally rely on surface water. To maintain their water use during droughts, agricultural and urban users can often supplement scarce surface supplies with extra groundwater pumping. In some cases, environmental water regulations are relaxed during droughts to make more surface water available for other uses (Hanak et al. 2015, Mount et al. 2017).

Beyond rectifying problems related to public misinterpretations of the official estimates, DWR could make several other adjustments to improve their accounts' usefulness. One issue is timeliness: long lags in the development of water use estimates limit their relevance. For example, no official estimates of environmental water use were available during the recent five-year drought. This fostered the perpetuation of myths about the burden environmental protections imposed on other users.

Another issue is transparency: DWR's water plan updates do not sufficiently describe the methodologies used to develop the estimates for different categories of applied and net environmental flows. For instance, the official water balances do not transparently account for flood flows and other instances of uncaptured flow, and do not explain methods for estimating applied versus net environmental water use.

A third, related issue is insufficient detail in the accounting of some categories of environmental flows. This is of particular note for required Delta outflows, a category that lumps together water for quite distinct purposes—keeping the Delta fresh enough for water diversions and protecting aquatic habitat for fish.

# Unpacking Environmental Water Uses

To effectively inform environmental water policy and management, state agencies need to develop water availability and use estimates in a timelier manner and adopt a more transparent and detailed approach to accounting for environmental water. This includes making the underlying methodology more explicit and the detailed data available for use by all interested parties. In addition, some changes in water use categorization would improve understanding and establish a better foundation for policy discussion and debate.

## Water Use Categories

Within any watershed, surface water flows can be apportioned into four broad categories:[3]

- **Water diversions:** Water reserved for diversion by water-right holders. The State Water Board and the courts supervise the use of this water.
- **System water:** Water required to support these diversions.[4] For example, some water must remain in rivers to offset seepage losses into groundwater basins through the river bed or losses due to evaporation. And in some rivers, a portion of the flow is needed to maintain water quality sufficient for diversions (this plays a major role in Delta water use, as described below). Water that needs to remain in rivers to cover conveyance losses is regulated under the water rights system. The State Water Board and Regional Water Quality Control Boards establish water quality related flows in water quality control plans, and include them in water rights permits and licenses issued by the State Water Board.

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[3] We focus here on surface water because it provides almost all environmental water use. In basin-wide water accounting exercises, it is also necessary to account for groundwater—a major source for agricultural and urban water diverters in some regions and years. Water balances also need to consider how groundwater and surface water interact—since rivers can be sources of groundwater recharge, and groundwater can augment river flows. Finally, water uses in any given period can be larger or smaller than the amount of water available from annual runoff because of changes in storage in surface reservoirs and aquifers. Surface reservoir releases are important for environmental water availability in California, and in some places—such as Yuba County—coordinated management of surface and groundwater storage contributes to environmental flows (see the Yuba River case study in the technical appendix to the companion report by Mount et al. 2017).

[4] We have borrowed the term "system water" from Victoria, Australia, where it is also known as "planned environmental water." For a description of environmental water use and allocation in Victoria see Mount et al. (2016).

- **Ecosystem water:** Water required to support fish and wildlife. These flows are primarily determined under the federal Clean Water Act and Endangered Species Act (ESA), and their state law counterparts. The flow requirements are administered by the State Water Board and federal and state fish and wildlife agencies.
- **Uncaptured water:** Water in excess of the three preceding categories. During most years and on most rivers—even during droughts—there are periods when river flows exceed either the capacity of existing storage and diversion facilities or the combined demands for water diversions, system water, and ecosystem water. Although some of this water is available under existing water rights (e.g., when water users have valid claims to the water but do not have the capacity to divert it because of infrastructure constraints), much of it constitutes flood flows that are not currently claimed under the water rights system.

The volumes in all of these categories vary across types of water years and seasons, depending upon the total volume of runoff and stored water available in upstream reservoirs and the seasonal pattern of demands. For example, irrigation diversions are highest in the late spring and summer, and ecosystem water requirements can vary depending on the seasonal needs of specific fish and wildlife. Uncaptured flows are most common during winter storms and spring snowmelt, but can occur in most months during wet years.

This proposed classification differs from DWR's current approach in two key ways. First, it makes an explicit distinction between regulatory requirements for system and ecosystem water. As described below, this is especially important in the Delta, where the current grouping of these two uses into a single category fuels misunderstandings and conflict. Second, it explicitly and systematically tracks uncaptured water—something not done well in DWR's current accounts.

## Accounting for Multiple Benefits

Depending on the specifics of the season and the watershed, some water can serve multiple, overlapping purposes. Some flows have sequential benefits. For example, water released from reservoirs to meet downstream demands for water diversions often plays a vital role in sustaining riverine ecosystems prior to reaching its destination.[5] Sometimes, flows can meet multiple objectives simultaneously. Rice farmers in the Sacramento Valley divert water to flood their fields in the fall to aid in decomposition of rice straw. This flooding (a water-right diversion to support agriculture) also creates seasonal wetlands for migratory waterfowl (an ecosystem benefit) (Strum et al. 2013). Requirements overlap significantly both for system water in the Delta (to meet diverters' water quality requirements) and for ecosystem water (to meet water quality and flow requirements for fish). Uncaptured water can also provide multiple system and ecosystem benefits, particularly during flood events. It can improve water quality, provide important habitat, and recharge groundwater basins.

To manage California's water resources most effectively for different and potentially competing objectives, it is important to identify opportunities for achieving multiple benefits with the same water. But an accounting framework also needs to avoid double- or triple-counting the volume of water put to use within the system. We therefore propose a hierarchy, which follows the order of water uses listed above: water diversions, system water, ecosystem water, and uncaptured water. In this approach, water assigned to the ecosystem is limited to the *incremental* or *net* volume of flows needed to meet regulatory requirements, in excess of water for diversions and system water. This does not diminish the role water diversions or system water can serve in meeting ecosystem

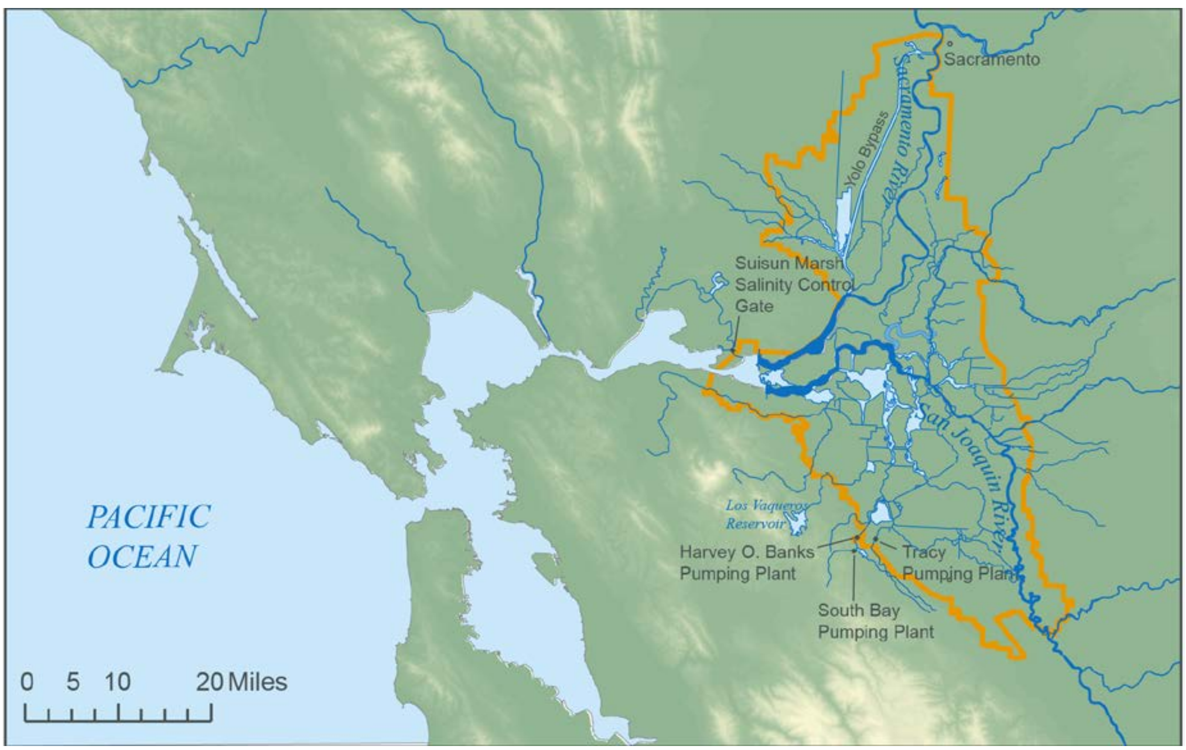
[5] The exception to multiple benefits of system water is where the water creates harm to ecosystems. Examples include releases of water from reservoirs that is too warm or nutrient rich, or releases that are out of phase with life cycles of freshwater species. Many hydropower reservoirs release pulses of water as they generate electricity. This daily rise and fall of water harms various aquatic organisms.

regulatory requirements, but it helps distinguish the cases where regulations lead to additional flow requirements. By definition, benefits provided by uncaptured water are above and beyond those required by environmental regulations for system and ecosystem water.

## Illustrating the Approach in the Delta

The Sacramento–San Joaquin Delta lies at the head of the San Francisco Estuary and at the confluence of the Sacramento and San Joaquin Rivers (Figure 2). Roughly half of all runoff in California flows down these rivers. About a third of this water is diverted upstream of the Delta for use by farms and some cities in the Sacramento Valley, on the east side of the San Joaquin Valley, and in the San Francisco Bay region.[6] Some of the water that flows into the Delta is used by local farms and cities (5%) or exported by the federal Central Valley Project (CVP) and California's State Water Project (SWP) to San Joaquin Valley farms and cities in the Bay Area, Southern California, and the San Joaquin Valley (17%). Of the remainder, some water flows into the San Francisco Bay and Pacific Ocean to meet system and ecosystem requirements. And in every year some additional uncaptured water flows out to the ocean.

**FIGURE 2**
The Sacramento–San Joaquin Delta




NOTE: The orange line shows the area defined as the "legal Delta" under state law. It is the area under the influence of tidal action.

[6] Delta water use statistics cited in this paragraph are averages for the period 2000-2015 (Mount et al. 2016).

In the sample accounting exercise below, we apportion water that reaches the Delta into the components described above—water diversions, system water, ecosystem water, and uncaptured flows—for 1980-2016. This 37-year period contains considerable hydrologic variability and spans some notable changes in regulations to protect fish and wildlife.[7]

We begin with what is included in each category and some caveats regarding the interpretation of results. We then highlight key takeaways from the analysis, and show how these results compare with both DWR's official estimates of required Delta outflow and a widely cited alternative estimate of Delta regulations costs to water exporters (MBK Engineers and HDR 2013). We provide details in Technical Appendices A and B and the data set *PPIC Delta Water Accounting*.[8]

## Apportioning Delta Inflows

Figure 3 illustrates an overview of how Delta inflows are apportioned into two types of water diversions—in-Delta use and exports—and three types of outflow: system water, ecosystem water, and uncaptured water.

### Water Diversions

In-Delta uses include net water use by farms and communities within the Delta and diversions by the Contra Costa Water District and the North Bay Aqueduct for communities in the surrounding area.[9] Delta exports include CVP and SWP exports from the south Delta pumps. Over this 37-year period, in-Delta uses averaged nearly 960,000 acre-feet annually, with a low of 73,000 acre-feet in 1983 (a very wet year when precipitation surpassed diversions by Delta farmers) to a high of nearly 1.5 million acre-feet (maf) in 1990, in the midst of a prolonged drought. Delta exports averaged 4.8 maf, with a low of 1.6 maf in 2015 at the height of the latest drought, and a high of nearly 6.8 maf in 2005, an above normal year.[10]

### System Water

The Delta's salinity—and the state's ability to use the Delta for water supply—is a product of the balance between freshwater outflow and the tides that bring salt water in from San Francisco Bay.[11] On average, water diversions upstream of the Delta take roughly a third of the flow that would reach the Delta if there were no diversions, and in-Delta use and exports take more than a fifth. The decline in outflow due to freshwater diversion and tidal action draws saline water into the Delta, reducing the quality of water for in-Delta and export uses. In its Water Quality Control Plans, the State Water Board sets salinity standards to protect in-Delta uses, including for farms and communities within and near the Delta. In addition, salinity must be kept low enough to allow exports from the CVP and SWP pumping plants in the south Delta.

The CVP and SWP have assumed the responsibility for meeting water quality standards in the Delta. They accomplish this through coordinated operations that release water from project reservoirs upstream of the Delta and through changes in export pumping rates at south Delta pumps.

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[7] In this exercise, we use data from January 1, 1980 to December 31, 2016. We primarily present the information in calendar years—rather than water years (which run from October 1 to September 30)—because this is more consistent with the way many of the Delta regulations are applied. However, when we compare our results with other exercises that use water year accounting, we convert our estimates to water years. The data set *PPIC Delta Water Accounting* provide the data in multiple time steps (daily, monthly, calendar year, and water year) to facilitate comparisons.

[8] These sources also provide estimates of the distribution of total flows within the greater watershed, including net upstream diversions and water held in storage, from 1995 to 2016 (technical appendix Figure B5).

[9] Net water use in the Delta is estimated as applied water use minus precipitation falling on the Delta.

[10] Exports in 1989 were nearly as high, even though this was a dry year in the midst of a prolonged drought.

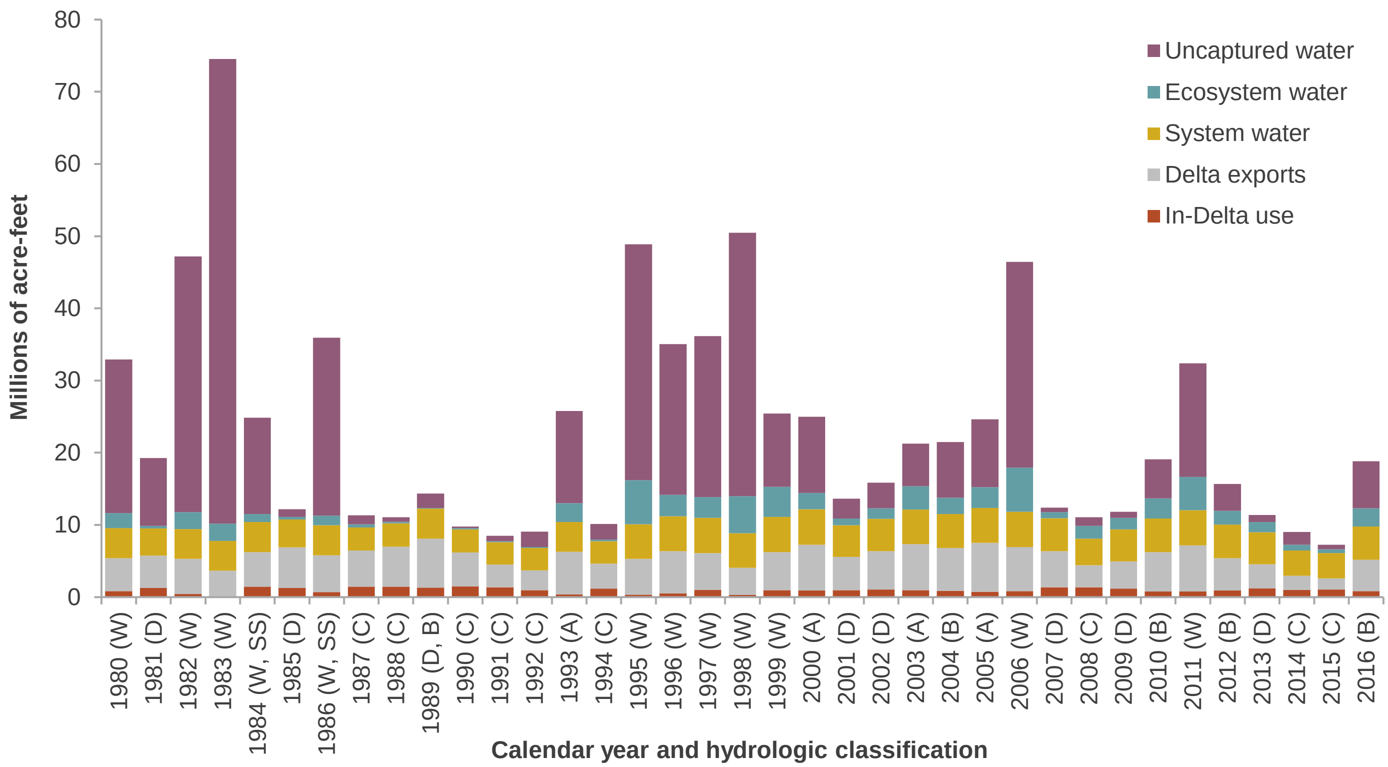
[11] Poor water quality in the San Joaquin River also affects Delta salinity. Runoff from San Joaquin Valley agricultural fields adds salt to the river, which increases the south Delta's salinity and impacts the balance between outflow and tides.

Maintaining the salinity balance so the Delta can be used for water supply requires sending large volumes of system water out of the Delta. We use a salinity model to estimate the volume of outflow needed to meet multiple, overlapping water quality standards for export water, Delta M&I, and Delta agricultural uses. Figure 3 groups these together into a single category of system water. On average, this outflow totaled more than 4.2 maf per year, with about 2.5 maf (60%) needed for export standards and the rest for in-Delta uses. The total ranged from a low of 3.1 maf in 1992 (a critically dry year) to 4.9 maf in 1999 and 2000 (wet and above-normal years, respectively).

The volume of outflow needed to meet salinity standards varies depending upon many factors, including time of year, water year type, tides, and the geographic location of specific standards. As shown below, these standards have been approximately the same over the period examined here, but the average amount of outflow needed to meet them has increased since the mid-1990s.

**FIGURE 3**

Where Delta water went, 1980–2016




SOURCE: Author estimates using multiple data sources. For details, see Technical Appendix B.

NOTES: The figure shows the apportionment of inflows into the Delta among various uses. Hydrologic classifications are based on State Water Board Decision 1485 (1980–1994) and Decision 1641 (1995–2016). W=wet, A=above normal, B=below normal, D=dry, C=critically dry. W, SS was a special designation for years with subnormal snowmelt under D1485, which had relaxed water quality standards. The year 1989 followed a critically dry year, and therefore had a dry classification for ecosystem flows, and below normal for system flows.

## Ecosystem Water

Populations of native fish that inhabit the Delta have declined, with some—such as delta smelt and winter-run Chinook salmon—on the brink of extinction (Sommer et al. 2007, Luoma et al. 2015, Moyle et al. 2012 and 2016). To improve ecosystem conditions in the Delta, the State Water Board's Water Quality Control Plans prescribe numerous, often overlapping, salinity and outflow standards.[12] Additionally, acting under their Endangered Species Act (ESA) regulatory authority, federal fish and wildlife agencies have imposed restrictions on CVP and SWP operations to improve conditions for fish. These regulations are contained in Biological Opinions (BiOps).[13]

Regulations to meet ecosystem objectives have changed over time (see Technical Appendix A for details). In 1978, the State Water Board's Water Rights Decision 1485 (D1485) set objectives that remained in place through 1994. Following litigation that successfully challenged the standards and the Bay-Delta Accord of 1994, the board adopted Decision 1641 (D1641), which set many standards still in place today. Federal BiOps were also established in the mid-1990s for several fish species, and in 2008 these underwent significant changes affecting export project operations.[14] Additional actions that changed allocation of ecosystem water included the federal Central Valley Project Improvement Act of 1992 (CVPIA), which set aside a portion of CVP water for ecosystem uses, and the federal Vernalis Adaptive Management Program (VAMP), an experiment in pulse flows to support salmon populations on the San Joaquin River. That program ran from 2000 to 2011.

These regulations resulted in three types of requirements that increase Delta outflow beyond the volumes required to meet system water needs:

- **Ecosystem flows.** Current regulations set standards for inflow to the Delta, as well as the volume of water that must become outflow to support fish habitat—such as pulse flows to help juvenile salmon migrate outward to the ocean. In this category we count the increment of outflow required above system water.
- **Ecosystem water quality.** Salinity plays a major role in habitat quality for some native fish species, and salinity standards are set to improve or protect this habitat. One of the most significant is the X2 standard, which prescribes where and when salinity is not to exceed approximately two parts per thousand.[15] In this category we count the incremental outflow needed to meet these standards above system water and ecosystem flow requirements.
- **Export pumping limits.** CVP and SWP operation of export pumps has direct and indirect impacts on ESA-listed species of fish. In addition, the BiOps at times restrict the timing and volume of pumping, even when the projects are meeting salinity and flow requirements. We have calculated the amount of additional ecosystem outflow generated by pumping restrictions, which increased significantly following the 2008 update of the BiOps.

Figure 3 combines these three categories into ecosystem water.[16] A significant portion of Delta outflow—on average nearly 2 maf per year—is assigned to improving ecosystem health and protecting native species of fish. This total ranges from a low of just 95,000 acre-feet in 1989 (in the midst of a multi-year drought) to a high of more than 6.1 maf in 1995 (a very wet year).

### Caveats on the interpretation of ecosystem water "costs" to Delta exports

The amount of ecosystem water varies with hydrologic conditions, and has also risen significantly over time. However, it is important to avoid misinterpreting these estimates, which show the volumes of water required to fulfill ecosystem regulations. In general, these required volumes of outflow are higher than the volume of water that the CVP and SWP must forego to comply with regulatory requirements. The availability of uncaptured water

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[12] The Water Quality Control Plan for the San Francisco Bay-Delta is undergoing revision. For an update, see the Water Quality Control Plan website.
[13] The Biological Opinions governing project operations are summarized at the US Fish and Wildlife website.
[14] The project operators are currently seeking re-initiation of Section 7 consultation under the ESA. This would lead to new BiOps governing future project operations.
[15] Pitzer (2014) provides a useful guide to understanding controls on Delta salinities.
[16] In Appendix B and the detailed data set, we break out export pumping limits separately from the combined category of ecosystem water quality and flows.

often makes it possible to meet the standards without reducing export pumping or water stored in project reservoirs. In addition, project operators can often limit the effects of regulations on exports—including those restricting pumping—by shifting the timing of exports to periods when regulations are less restrictive.

Management flexibility is much more limited in dry and critically dry years, when less water is available and Delta water is managed tightly to the limits that regulations allow. In those years, ecosystem water requirements approximate the actual cost of environmental regulations to export operations. The impact of ecosystem regulations in other years has likely grown since the late 2000s, as export pumping limits have increased and become more restrictive.

### Multi-purpose water: system water's role in meeting ecosystem regulatory standards

Because our calculations show the net amount of water required for ecosystem-related regulations—above the volumes required to flow out of the Delta to meet system water needs—it is also useful to highlight the contribution of system water to meeting ecosystem requirements. On average, most system water (83%) also helped fulfill ecosystem flow and water quality requirements. In Technical Appendix B and the accompanying spreadsheets, we refer to this as "multipurpose" water.[17] This share is less than 100 percent because system water requirements sometimes exceed ecosystem requirements, particularly during the fall.

## Uncaptured Water

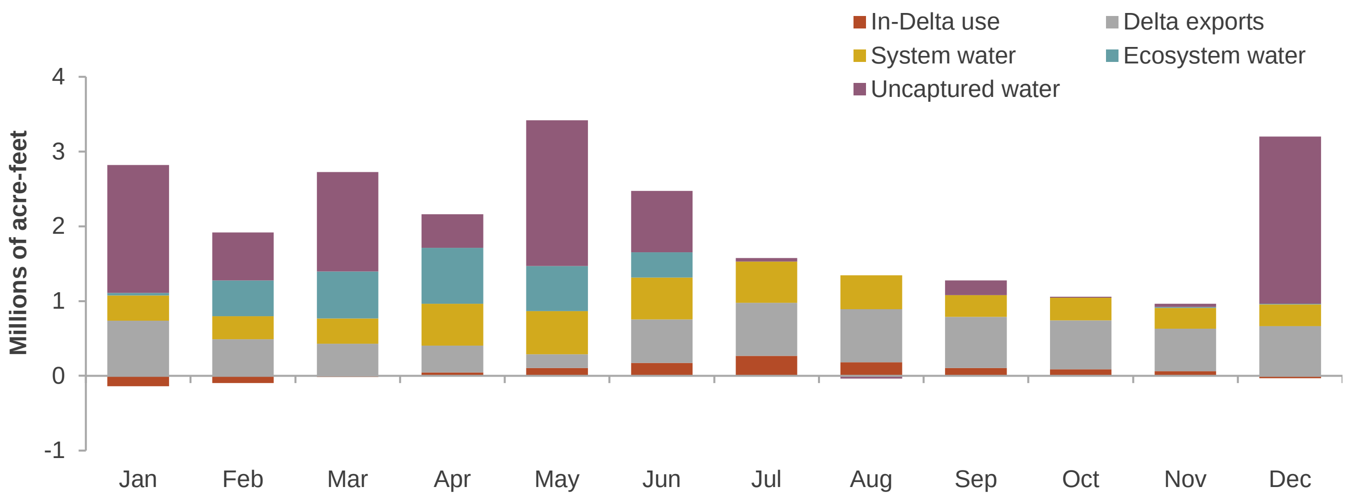
In all years analyzed for this study, there are periods when inflows to the Delta exceed the demand for water or the capacity to divert it. This uncaptured water occurs most often during the winter when upstream reservoirs are required to release storm water to maintain their flood control reserve, or when large snowpacks melt in the spring. Figure 4 illustrates this seasonality across 2005, a year of above-normal runoff. Uncaptured water volumes are highest during wet years and lowest during droughts, when upstream reservoirs have more unused capacity to store runoff. But even during the driest year analyzed here (2015), uncaptured water was significant (nearly 630,000 acre-feet) due to flow on undammed tributaries. Not surprisingly, uncaptured water is the most variable category of Delta water uses. It averaged 11.3 maf over the 1980–2016 period, with a low of 221,000 acre-feet in 1990, during an extended drought, and a maximum of over 64 maf in 1983, the wettest year in the sample.

Uncaptured outflow plays a critical—and underappreciated—role in Delta water management. The events that lead to uncaptured outflow reduce the amount of water the CVP and SWP must release from reservoirs to meet salinity and flow requirements for system and ecosystem water regulations. During extended uncaptured flow events, export pumping restrictions are often relaxed as well.

[17] For details, see technical appendix Figure B7 and the related discussion. In the data set *PPIC Delta Water Accounting*, this overlapping category appears as "multipurpose water" in the summary tables.

FIGURE 4

Uncaptured outflows are generally highest during the winter and spring




SOURCE: For details see technical appendix Figure B1.

NOTES: In-Delta use includes diversions from the North Bay Aqueduct and the Contra Costa Water District and net in-Delta water use, minus precipitation. When this value is negative, precipitation exceeded the other diversions. Negative uncaptured water results when outflow is lower than the average required to meet water quality standards. This often occurs in months that have large changes in water quality standards (August, for example, when the In-Delta agricultural standard stops on August 15) and the CVP and SWP increase exports (and reduce outflow) for a period while the salinity levels rise in the Delta.

## Key Takeaways from this New Accounting Approach

Using our proposed accounting methods, we have tracked the allocation of inflow to the Delta between water diversions, system water, ecosystem water, and uncaptured water for a 37-year period. Table 1 summarizes how the volumes of water in each category vary over this period, reflecting natural variation in inflows to the Delta and changing environmental regulations to address declines in native fish populations. The table groups the results into three main regulatory periods:

- 1980–94, when the State Water Board's D1485 was the primary driver of both system and ecosystem water requirements.
- 1995–2007, when the State Water Board's D1641 was the primary regulatory driver. System water requirements did not change relative to D1485, but ecosystem water requirements did. During this period, the federal BiOps and other laws also had a relatively modest additional effect on ecosystem outflow.
- 2008–16, when D1641 was still in effect, but the BiOps were also updated, increasing requirements for ecosystem water, particularly with more restrictions on export pumping.

**TABLE 1**

Distribution of Delta inflows in different periods and water-year types (1980–2016)

| Period and year type | Number of years | Total inflows (maf) | Delta diversions (maf) | | System water (maf) | Ecosystem water (maf) | | Uncaptured water (maf) |
|---|---|---|---|---|---|---|---|---|
| | | | In-Delta uses | Delta exports | | Flow and water quality | Export pumping limits | |
| **D1485 (1980–94)** | | | | | | | | |
| Critically dry | 6 | 10.0 | 1.3 | 4.1 | 3.2 | 0.2 | 0.0 | 1.2 |
| Dry | 2 | 15.7 | 1.3 | 5.1 | 3.8 | 0.3 | 0.0 | 5.2 |
| Below normal | 1 | 14.4 | 1.3 | 6.8 | 4.2 | 0.0 | 0.1 | 2.0 |
| Above normal | 1 | 25.8 | 0.4 | 5.9 | 4.1 | 1.4 | 1.3 | 12.8 |
| Wet | 5 | 43.1 | 0.7 | 4.6 | 4.1 | 1.4 | 0.5 | 31.8 |
| **D1641 (1995–2007)** | | | | | | | | |
| Dry | 3 | 14.0 | 1.1 | 5.0 | 4.5 | 0.7 | 0.4 | 2.3 |
| Below normal | 1 | 21.5 | 0.9 | 5.9 | 4.7 | 1.8 | 0.4 | 7.7 |
| Above normal | 3 | 23.6 | 0.9 | 6.5 | 4.9 | 1.7 | 1.0 | 8.6 |
| Wet | 6 | 40.4 | 0.6 | 5.2 | 4.8 | 3.5 | 1.0 | 25.2 |
| **D1641 & post-2008 ESA (2008–16)** | | | | | | | | |
| Critically dry | 3 | 9.1 | 1.1 | 2.2 | 3.6 | 0.5 | 0.6 | 1.2 |
| Dry | 2 | 11.6 | 1.2 | 3.5 | 4.4 | 0.9 | 0.6 | 0.9 |
| Below normal | 3 | 17.9 | 0.8 | 4.8 | 4.6 | 0.9 | 1.5 | 5.2 |
| Wet | 1 | 32.4 | 0.8 | 6.4 | 4.8 | 3.0 | 1.6 | 15.7 |

SOURCES: Technical appendix Table B3 and related discussion.

NOTE: The data are reported in calendar years.

To clarify the changes in ecosystem water over time, the table distinguishes between quantities required to meet flow and water quality regulations and those resulting from explicit export pumping limits. In each period, estimates are reported by the hydrologic classifications of water years, which govern some of the rules regarding both system and ecosystem water. Although this facilitates comparisons across periods and year types, it is important to bear in mind that the sample size in many years is limited, and conditions can vary considerably across years with the same hydrologic classification.[18]

This analysis yields five key conclusions that improve understanding of how water flowing into the Delta is apportioned:

- **System water requirements are large.** It takes a large volume of outflow from the Delta to maintain salinities low enough for in-Delta uses and CVP and SWP exports. In dry and critically dry years since 2008 (current regulations), every acre-foot of diversions required an equal amount of water flowing out of the Delta to hold back salt water. This outflow is essential for water supply, and would be required even if there were no ecosystem management objectives in the region.
- **System water requirements are growing.** Since the mid-1990s an additional 400,000 to 600,000 acre-feet per year of system outflow has been needed to maintain Delta salinity standards. The causes of this increase are uncertain, but may include sea level rise, changing channel hydrodynamics, and changes in

[18] As a simple illustration, compare how average inflows vary across regulatory periods for the same hydrologic year types in Table 1.

operations. Further investigation is warranted to understand the reasons for this increase, which has likely reduced available supplies for Delta exports in some years. Additional increases in system water to repel salinity can be expected with the anticipated acceleration in sea level rise in the coming decades.[19]

- **Ecosystem water requirements have risen.** In all three periods, the proportion of outflow assigned to the ecosystem varies considerably across different types of water years. But the amount of ecosystem water has also increased significantly over time. Prior to the mid-1990s, the additional water required to protect the ecosystem was fairly small, especially during drought.[20] Ecosystem water increased significantly under D-1641 and again with the implementation of the ESA BiOps in 2008. In this most recent period, explicit export pumping limits to reduce harm to endangered fish increased across all year types.
- **Costs of ecosystem water to Delta exports vary between wet and dry years.** During wetter years, ecosystem outflows are substantial. However, as noted above, in many years this increase does not lead to a proportional decline in exports since nature provides enough flow to meet salinity and flow standards. The volume of ecosystem water declines dramatically during dry and critically dry years, but these outflow requirements generally represent a direct cost in terms of reduced exports. Although CVP and SWP managers also have some ability to limit the cost of export pumping restrictions by shifting pumping schedules, regulatory changes since the 2008 BiOps update have reduced this flexibility and increased trade-offs between ecosystem water and exports in wetter years.
- **Uncaptured water provides multiple benefits.** Outflow from the Delta above system and ecosystem needs is traditionally viewed as a lost water supply opportunity. Yet this water provides multiple benefits, both within the Delta and the San Francisco Bay (Cloern et al. 2017), and it is critical for the projects' salinity management. Future efforts to expand storage and water use upstream of the Delta that reduces uncaptured outflow may have unintended consequences for Delta water supply and ecosystems.

## How Our Findings Compare to Other Approaches

Here we compare our findings to two other recent efforts that account for environmental water in the Delta: DWR's official estimates of required Delta outflow that appear in the California Water Plan Update (Department of Water Resources 2013) and a widely cited alternative estimate of the costs of Delta regulations to water exporters (MBK Engineers and HDR 2013). The latter issue is of keen interest to water users, and the MBK analysis is the basis of a recent widely circulated study by the Brattle Group that estimates the economic costs of environmental regulation in the Delta because of reduced Delta exports (Sunding 2017).

### Comparison with DWR's Estimates of Environmental Water Use in the Delta

As noted above, DWR's estimates of environmental water requirements in the Delta do not distinguish among the different purposes of regulations. We have emphasized the value of disaggregating this total to improve understanding of the roles of regulations and the potential flexibility for improving management and outcomes. Figure 5 compares our estimates with DWR's for the years when both series are available (1998–2010).[21] To facilitate comparison, we have broken our estimates into system water and two categories of ecosystem water: flow and water quality requirements, and export pumping limits.

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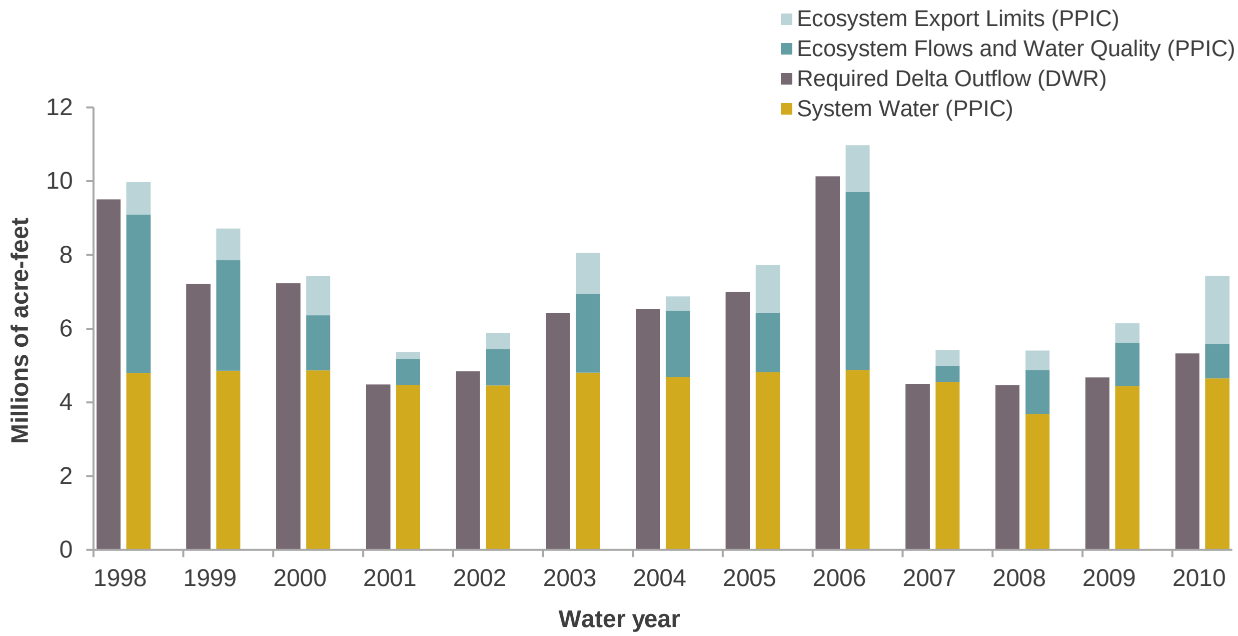
[19] Fleenor et al. (2008) show that a one foot increase in sea level rise relative to 1981–2000 conditions—a level within the range expected by the mid-21st century—could require increases in outflow of 475,000 acre-feet to maintain system water salinity standards. MacWilliams et al. (2016) show that salinity will migrate eastward into the Delta under current operations with as little as 6 inches of sea level rise.

[20] During the 1987–92 drought, ecosystem standards resulted in little additional outflow beyond that needed to meet system water requirements (Figure 3 and Table 1). In 1989, during the middle of the drought, CVP and SWP exports were the highest seen to date. The high export volumes during this drought may have permanently changed the Delta ecosystem. For an analysis of impacts of drought and water operation on biological invasions see Winder et al (2011).

[21] DWR uses water years for their accounting (October through September). For this comparison we have adjusted our results to match their approach.

**FIGURE 5**

Comparison of 2013 California Water Plan and PPIC estimates of Delta environmental water




SOURCES: California Water Plan Update (Department of Water Resources 2013) and Technical Appendix B.

NOTE: Values are total volume for water years (October–September).

Although the studies used different analytical approaches, their estimates are broadly comparable. One key difference, however, is that DWR did not include the additional outflows that occur because of ecosystem-related limits on export pumping. As a result, DWR underestimates the total outflow resulting from Delta environmental regulations.[22] In addition, DWR's aggregation of system and ecosystem water into a single category can foster misunderstandings of the purposes of environmental regulation in this region.

Our results show that in many years—particularly dry years—most environmental water is system water, required to maintain salinities for in-Delta and export uses. This separation of system water from ecosystem water gives a more accurate accounting of the use of environmental water.

## Comparison with MBK Engineers' Estimates of Regulation Costs to Delta Exports

The MBK study took a very different approach from ours—focusing on the reductions in CVP and SWP export deliveries due to changes in environmental regulations following the 1995 implementation of Decision 1641 and the 2008 update of the BiOps. It used regulatory requirements in place under Decision 1485 as a baseline for comparison. Unlike our study, which examined actual operations and outflow over a relatively short period of time, its authors simulated regulation-based reductions in export volumes based on water year type, using hydrology for the 1992–2003 period (see Technical Appendix B for a full description). Because regulations

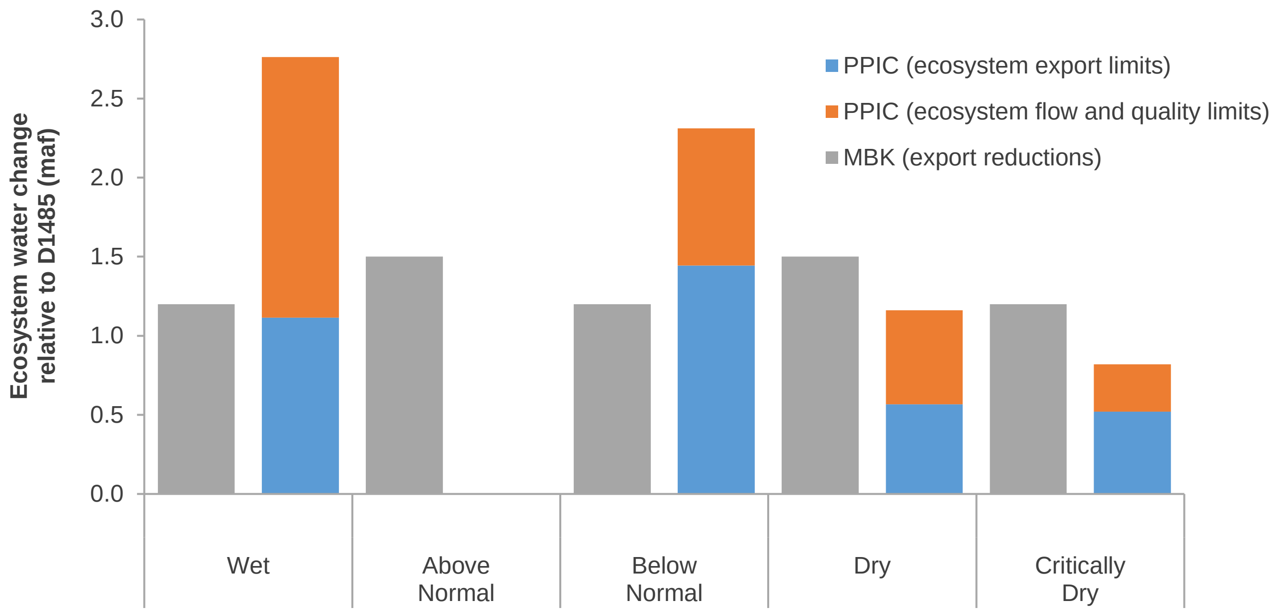
[22] There are two other main differences in DWR's methods relative to ours. First, in calculating the X2 requirements for fish, DWR's method results in slightly higher ecosystem water than is required by regulation, because it does not include carryover days. (Under X2 requirements, if the number of days where the X2 location is actually met exceeds the required number, the extra days carry over to the next month, reducing the requirement that month). On the other hand, DWR's method underestimates system water requirements, because it does not include the portion of system water that exceeds ecosystem flow and water quality requirements. As shown in technical appendix Figure B7 and the related discussion, fall system water needs are often slightly higher than ecosystem flow and water quality needs.

regarding system water have not changed since the adoption of D1485, the MBK study attributed all subsequent changes in water available for exports to ecosystem-related regulations.

Despite these differences in approach, it is useful to compare the two studies. In Figure 6 we compare MBK's estimated reductions in exports with our estimates of changes in ecosystem water under current regulations in effect since 2008.[23] To facilitate the comparison, we again distinguish between outflow resulting from export pumping limits and outflow resulting from ecosystem flow and water quality-related rules. Because export pumping limits are generally more likely to reduce Delta exports, Figure 6 displays these as the bottom category in the stacked bars.

**FIGURE 6**

Comparison of MBK and PPIC estimates of increases in ecosystem water requirements under current regulations compared with pre-1995 regulations




SOURCES: MBK Engineers and HDR (2013) and Technical Appendix B.

NOTES: The figure shows estimates for water years. It compares requirements for current regulations (including D1641 and the 2008 updated BiOps) relative to requirements under D1485, in effect before 1995. The PPIC estimates are for a smaller set of actual years, whereas the MBK estimates are simulated results for a longer hydrologic record (see text). During 2008–16 there were no above-normal years and hence no PPIC estimates of changes in ecosystem water relative to 1980–94, when D1485 was in effect.

This comparison yields several key conclusions:

- Both studies show increases in ecosystem water requirements.
- During dry and critically dry years, the studies find similar effects from changing regulations. This is consistent with our contention that ecosystem outflow requirements are most likely to reduce exports in dry times. However, the MBK estimates of export reductions are approximately 400,000 acre-feet higher than our estimates of increased ecosystem outflow. The MBK study may have counted the increase in system water required to keep the Delta fresh enough for diversions as a cost of ecosystem regulations. If this is so,

[23] Table 1 illustrates the volumes required by regulations in the three different periods in our estimates, which we have converted to water years in Figure 6 to facilitate comparison with the MBK results. Technical appendix Figure B11 also shows a comparison of results for 1995–2007, when D1641 was in operation with the earlier BiOps.

the MBK study (along with related economic analyses) overstates the impacts of environmental regulations on exports during drier years.

- In years that are not classified as “dry” or “critically dry,” our estimates of ecosystem water increases are much larger than MBK’s estimates of export losses. However, our estimates of outflow volume generated by export pumping limits are comparable to MBK’s estimates. This is consistent with our observation that uncaptured outflows often meet ecosystem flow and water quality regulations when water availability is higher. Pumping restrictions can still significantly reduce total exports in these years, as they did following the 2008 update of the BiOps.

## Conclusion

Our proposed new environmental water accounting approach for the Sacramento–San Joaquin Delta reveals details and insights that cannot be easily understood from DWR’s current methods in its updates of the California Water Plan. DWR’s approach combines system and ecosystem water and does not explicitly consider the role of uncaptured water in different types of water years. Ours presents a richer and more nuanced picture, considering four broad types of water uses—water diversions, system water, ecosystem water, and uncaptured flows. Our distinction between system and ecosystem water may be most significant for the Delta, given the importance of salinity control for water diversions in that region. But we believe there is also value in extending this approach to other watersheds and regions. This means unpacking and clarifying the uses of water now assigned to wild and scenic rivers, instream flows, and wetlands in DWR’s environmental water accounts.

In upstream portions of watersheds, such as rivers upstream of the Delta, it will be especially important to distinguish between the volumes of environmental water consumed locally (net water use) and the volumes that flow further downstream and become available for reuse. DWR’s current accounts are not transparent in this regard. For instance, a large portion of flows in upstream segments of wild and scenic rivers in the Sacramento and San Joaquin Valleys is counted as net environmental water use, even though these river segments flow into reservoirs used for downstream water supply. When high flow conditions require these reservoirs to release water to downstream areas in excess of the demands of water diverters, it should be counted as uncaptured water, not water dedicated to the environment.

It will also be helpful to track how different categories of water serve multiple, overlapping purposes in different watersheds. In the Delta, the key area of overlap is between system and ecosystem water requirements, both of which reduce salinity and augment the volume of water flowing through the Delta to the ocean. In upstream areas, there is more likely to be overlap between water kept in rivers for downstream diversions and water used to meet ecosystem needs. For example, there are synergies between water released to maintain cold water for salmon below Shasta Dam and water used for irrigation by Sacramento Valley rice farmers in the spring. Fostering an understanding of where such benefits exist can encourage creative thinking about how to use scarce water most effectively to meet a range of needs.

More generally, California needs greater clarity on the methods used to estimate different categories of environmental water, as well as more detailed presentation of the underlying data. This would enable various parties to cross-check DWR’s analysis and use the information in their management decisions. More timely release of the accounts—particularly for key watersheds like the Delta—is also imperative to reduce conflict and create a shared understanding of how the system works. We hope our example of Delta water accounts through

2016—developed with limited staff resources using publicly available data and models—can be a model of what is possible elsewhere.

A more timely, transparent, and detailed environmental water accounting approach along the lines proposed here can also play an important role in ongoing efforts to improve ecosystem water allocations. In the companion report to this study (Mount et al. 2017), the authors recommend the establishment of ecosystem water budgets that can be flexibly managed, stored, and traded. Development of these budgets will be critical to efforts to monitor the use and effectiveness of ecosystem water.

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# Managing California's Freshwater Ecosystems

## Lessons from the 2012–16 Drought

## SUMMARY

## CONTENTS



Technical appendices to this paper are available on the PPIC website.


The 2012–16 drought caused unprecedented stress to California's ecosystems and pushed many native species to the brink of extinction. It also tested the laws, policies, and institutions charged with protecting the environment.

Eight case studies on environmental water management during the drought reveal both strengths and weaknesses in federal, state, and local response that can inform how California addresses future droughts. Three areas of reform hold promise for improving ecosystem conditions and reducing conflict:

- **Improve water accounting.** Drought management requires accurate and timely information about water use and availability and about likely environmental response to changes in water supply. But California's current tracking systems are neither timely nor transparent. To address these gaps, environmental water accounting and ecosystem monitoring systems need an overhaul.
- **Prepare for drought.** With a few significant exceptions, environmental water managers were unprepared for the environmental consequences of an extended drought, and were forced to make ad hoc decisions during a crisis. Developing watershed-level plans that set ecosystem priorities and identify trade-offs would help managers anticipate drought and drive implementation of habitat investments and water allocation. Annual watering plans that guide management under different types of water years would better engage and inform water users.
- **Develop ecosystem water budgets.** Current methods of allocating water to support ecosystem health rely on minimum flow standards that are unevenly enforced and often insufficient during drought. Ecosystem water budgets, which allocate a portion of water to the ecosystem within watersheds, could enable more flexible and effective water management during dry times.

Although state and federal agencies have important roles in implementing these reforms, negotiated settlement agreements involving water users, environmentalists, and other key stakeholders hold the most promise for initiating durable and effective new approaches.

# Introduction

The allocation of water for multiple, often competing uses remains one of California's greatest water management challenges. The state's variable climate—with its long, dry summers and frequent multi-year droughts—ensures that water scarcity affects all sectors. The 2012–16 drought was unprecedented in its combination of warmth and dryness. It exposed weaknesses in drought preparations and tested the capacity of federal, state, and local institutions to maintain flow and water quality necessary for ecosystem health. The severity of the drought and scarcity of available water put many species of freshwater fish on the brink of extinction (Hanak et al. 2015, Mount et al. 2015). Yet allocation of water to the environment—even though required by federal and state laws—was seen by many as taking water from essential human uses, especially irrigated agriculture.

The controversy over environmental water allocation highlighted the challenges California faces as it tries to balance economic, social, and ecosystem uses of water—challenges that will become more acute as the climate continues to change.[1] Neither water users nor environmental interests are satisfied with the state's current approach. Many environmental advocates point to continued decline in native species populations and the habitats they depend upon. In their view, the state has failed to protect public trust resources adequately, and consistently favors urban and agricultural uses at the expense of freshwater fish and wildlife.

In contrast, many in the water user community believe they are unfairly burdened by environmental protections. They argue that large amounts of water have already been redirected to the environment, with little evidence that native species are recovering. Given the many sources of risk already faced by farmers—who rely on large volumes of water for irrigation—future environmental water allocations are an additional uncertainty.

That environmental water allocation is not working well for anyone should not be a surprise, given the intense competition for limited water supplies in California, the scale of environmental degradation, and the tradeoffs inherent in many water management decisions. Although it is unlikely that a solution can ever be found that completely satisfies all parties, there may be ways to reduce the intensity of conflict while reducing risk to both the environment and water users.

In this report, we draw lessons from the 2012–16 drought to explore approaches that can help Californians improve the efficiency and effectiveness of freshwater ecosystem management for future droughts. We begin by describing why native freshwater-dependent species have become so vulnerable to drought, even though they evolved in a highly variable climate. We then present an overview of key characteristics of this drought, its impacts on freshwater ecosystems, and the nature of institutional responses as the drought unfolded. This review focuses on eight case studies, which illustrate a range of management approaches by local, state, and federal agencies.

The insights from these case studies inform our recommendations for a package of three mutually reinforcing policy reforms to improve the health of California's freshwater ecosystems:

- **Improve environmental water accounting and monitoring.** Better tracking of water availability and use, and better monitoring of ecological conditions, can reduce conflict and improve decision making. As an example, we present a detailed accounting of environmental water in the Sacramento–San Joaquin Delta from 1980–2016, which dispels some common misperceptions about the tradeoffs between water use for ecosystems and other water users during drought.
- **Plan and prepare for droughts.** In contrast to the urban and agricultural sectors, there was little preparation to lessen the effects of drought on California's freshwater ecosystems. Reducing harm to fish

[1] Social uses include recreational activities like swimming, fishing, and cultural appreciation of waterways and nature.

and wildlife during drought requires advance planning, setting priorities for the allocation of scarce water supplies, and reducing various sources of stress that are magnified by drought.

- **Establish ecosystem water budgets.** California's current approach to allocating water to ecosystems generally involves setting minimum flow and water quality standards that focus on the needs of one or more endangered species. This approach is not working, particularly during drought. A more promising alternative is to allocate a portion of water to the ecosystem within watersheds. These ecosystem water budgets (EWBs) would function like water rights—with the same opportunities for flexible management, storage, and trading. They would be managed by ecosystem trustees at the watershed scale.

For each reform, we describe the basic elements and options, and identify roles and responsibilities for various agencies and stakeholders. Although state and federal agencies have important roles, negotiated settlement agreements involving water users, environmentalists, and other key stakeholders hold the most promise for initiating durable and effective new approaches. We then outline key legal and funding issues, and end with a brief conclusion.

This work builds upon recent research efforts at PPIC on freshwater ecosystem management and drought.[2] We have also benefitted from the insights of a diverse array of representatives from state and federal planning and regulatory agencies, water user groups, environmental groups, and researchers. They joined us in summer 2016 for an all-day workshop on the concepts presented here, and participated in subsequent discussions. A technical appendix provides more details for the eight case studies, and a companion report by Gartrell et al. (2017), *A New Approach to Environmental Water Accounting: Insights from the Sacramento–San Joaquin Delta,* elaborates on the environmental water accounting approach proposed here.

## Why California's Freshwater Ecosystems are Vulnerable to Drought

California's native plants and animals that depend on freshwater ecosystems are adapted to a highly variable climate with strong but predictable seasonal and regional variations in temperature, precipitation, and runoff. These include cool, wet winters—with snow in the mountainous regions—and warm, dry summers. Multi-year droughts are common. Since reliable hydrologic record-keeping began in the late 1800s, three extended droughts have lasted five or more consecutive years (1928–35, 1987–92, and 2012–16).[3]

Adaptation of native species to drought comes in many forms, including behavioral responses and physiological characteristics to avoid, cope with, or quickly recover from drought. Drought-adaptive traits exist in many of the state's freshwater-dependent species, including fish, insects, amphibians, and birds, as well as riparian and wetland plants (Table 1 provides examples for native fish). California's natural hydrology was a series of boom and bust years, with great expanses of freshwater habitats available in wet periods, and much less habitat during

[2] This includes an assessment of drought impacts (Mount et al. 2015, Hanak et al. 2015). It also includes recommendations to reform the way the state allocates water to all sectors, including the environment (Gray et al. 2015), recommendations for modernizing water accounting (Escriva-Bou et al. 2016), and comparisons of California's approach to ecosystem management during drought with those of Victoria, Australia (Mount et al. 2016a).

[3] These are droughts with consecutive dry years. Drought-like conditions—involving multiple dry years punctuated by a few wet years—are also common. Since the end of the Ice Age 12,000 years ago, California has experienced several mega-droughts that have lasted more than a century (Ingram and Malamud-Roam 2013). California is currently in a dry period that began in 2000. Since that time, only one third of the years have been above the long-term average for statewide precipitation.

dry periods. Although populations of native species undoubtedly declined during droughts, subsequent wet periods allowed for their rapid recovery.

The ability of native species to adapt to and recover from drought, however, has changed. Historic land and water use has dramatically reduced the quality and quantity of habitat. Reduced flows below reservoirs, the construction of barriers within rivers, and the disconnection of rivers from their floodplains and wetlands by levees means that many native species experience the equivalence of drought conditions in all but the wettest years, and are unable to take advantage of their drought adaptations. This inhibits population recovery following severe drought and amplifies the effects of droughts when they occur.

**TABLE 1**

California freshwater fishes' biological adaptations to drought, and why they are no longer working

| Drought Adaption | Common Species | Why Not Working |
|---|---|---|
| **Anadromy.** Anadromous fishes spend a portion of their life cycle in the ocean. This ensures that some of their population is in the ocean when inland conditions are poor, enabling them to return when spawning and rearing conditions improve. This is a hedge against poor ocean conditions, when good inland conditions can support populations. | Chinook and coho salmon, steelhead, cutthroat trout, green and white sturgeon, Pacific and river lamprey | Populations decline if conditions are consistently poor in one environment or the other. Ocean conditions—when good—cannot compensate for long term changes in inland conditions due to dams, river habitat loss, and watershed management. This leads to population declines. |
| **Fecundity.** Although populations decline during drought, fecund fishes take advantage of abundant habitat during wet conditions through exceptionally high rates of reproduction. | Longfin smelt, Sacramento splittail, salmon, green and white sturgeon, suckers | Abundant, high quality habitat is no longer available during wet periods due to land use changes, flow regulation, and diversions. Species cannot recover populations during periods of favorable conditions. |
| **Longevity.** Long-lived fishes wait out droughts and reproduce during periods when conditions improve for spawning and rearing. | Green and white sturgeon, Sacramento splittail, pikeminnow, suckers, tui chubs | Land management and water storage and diversion practices leave rivers and estuaries in drought-like conditions in most years. This lengthens the time between good years for reproduction. |
| **Tracking.** Some estuarine fishes are able to migrate with changing salinity gradients when freshwater runoff declines. | Delta smelt, longfin smelt, splittail, prickly sculpin | Reductions in inflows to estuaries, physical transformation of the Delta, and changes in food web productivity limit habitat availability during drought. |
| **Long-distance movement.** Some anadromous fishes are able to travel long distances to reach suitable habitat during drought, such as headwater areas with reliable cold water springs. | Spring- and winter-run Chinook salmon, steelhead trout | Dams have blocked access to most headwater areas that have reliable cold water sources and flows critical to drought survival. |
| **Dispersal.** During dry years, fish may be confined to reduced habitat areas; during wet years they disperse to improved habitats quickly, through movement and reproduction. | Most native fishes | Dispersal is blocked by dams, diversions, and perpetually dry streams. |

SOURCE: Based on authors' experience working in California.

NOTES: Fish and wildlife have a variety of life-history strategies that allow them to adapt to and recover from droughts. Modern land- and water-management practices work in contravention of many of these adaptations, inhibiting their recovery from drought.

Although habitat loss and flow changes are some of the most visible impacts on native species, other factors—part of a suite of "multiple stressors"—contribute to the loss of capacity for recovery following drought (Mount et al. 2012). For example, during drought, diminished flows concentrate pollutants that affect food webs and native fish. Warm conditions and low flows are also often accompanied by blooms of toxic algae, high water temperatures, and low dissolved oxygen that are harmful to many fish. Introduced non-native species are often better adapted to the changes in flow, physical habitat, and water quality of California's freshwater ecosystems. During drought, these invasive species will often proliferate, harming the food webs that support native species or altering their physical habitat. Finally, fisheries management practices—including harvest control and use of fish hatcheries—reduce the capacity of some fish populations to recover from drought.

These multiple, interacting stressors are the ultimate cause of declining populations of native freshwater plants and animals in California. These stressors can be present during all water year types, making it important to take a comprehensive "all of the above" approach to recover and sustain native species. Drought warrants particular attention, however, because it is a critical bottleneck for populations, and species' adaptations to drought are less effective in today's highly managed ecosystems.

# The 2012–16 Drought: Ecosystem Impacts and Institutional Responses

The five-year period from 2012–16 provides a useful test of institutional response to water scarcity. This drought affected the entire state for most of its duration, which is unusual compared with most previous droughts (Hanak et al. 2015). The one exception was 2016, when Northern California received precipitation close to historical average, while central and southern California remained exceptionally dry. Drought impacts on freshwater ecosystems were also widespread, and management and regulatory institutions were challenged to respond effectively.

## Drought Conditions and Effects on Freshwater Ecosystems

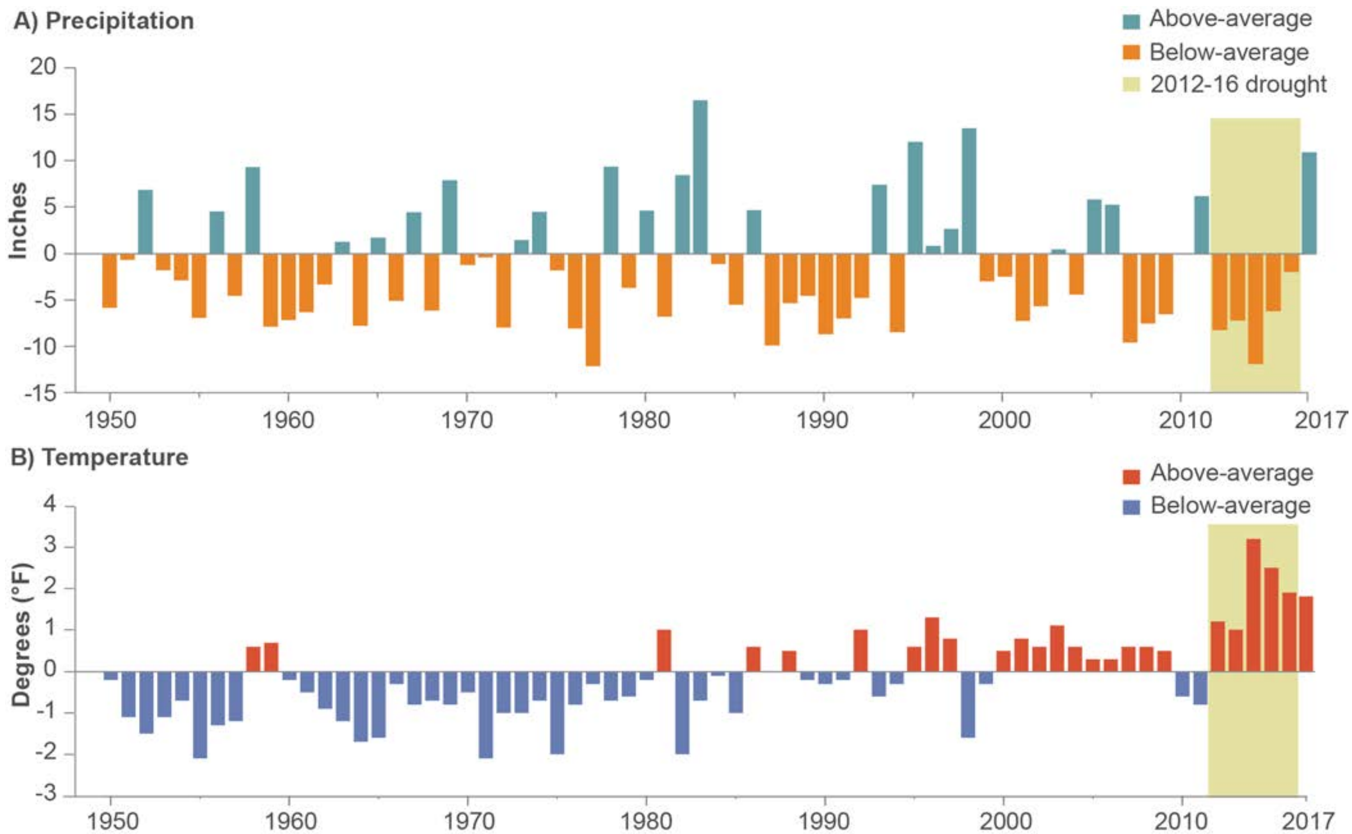
The 2012–16 drought had significant impacts on the state's freshwater ecosystems. This stemmed from:

- **Record dryness.** Although the drought did not contain the driest single year on record, 2012–15 was the driest cumulative four-year period in California history (Figure 1). Consecutive years of drought have far greater effects on ecosystems than individual exceptionally dry years.
- **Record warmth.** The drought was the warmest five-year period on record, and 2014, 2015, and 2016 were the three warmest years ever (Figure 1). These high temperatures affected water quality and quantity throughout the state.
- **Record low snowpack.** The combination of little precipitation and record high temperatures diminished snowpacks, notably on the west slope of the Sierra Nevada, the most important region for the state's water supply. Winter 2014 saw a record low snow water equivalent (a measure of the amount of runoff available in snowpack), and then winter 2015 broke the record again. Peak snowmelt runoff also occurred much earlier than average in all five years.[4]
- **Unusually wet conditions before and after.** What happens before and after a drought is important to ecosystem management. Water year 2011 was a wet and cool year, particularly in Northern California. Reservoir storage matched record highs during 2011 and cool spring and early summer conditions benefitted aquatic ecosystems. The drought broke with above average precipitation in water year 2017, including record precipitation totals in parts of Northern California.

[4] There has been debate over the magnitude of this drought and its historical precedence, with suggestions that it was a one-in-1,500 year event. For a discussion of this—including the tendency to overstate the recurrence intervals of severe climatological events—see Lund (2015).

**FIGURE 1**

Record dryness and warmth characteristics of the 2012–16 drought



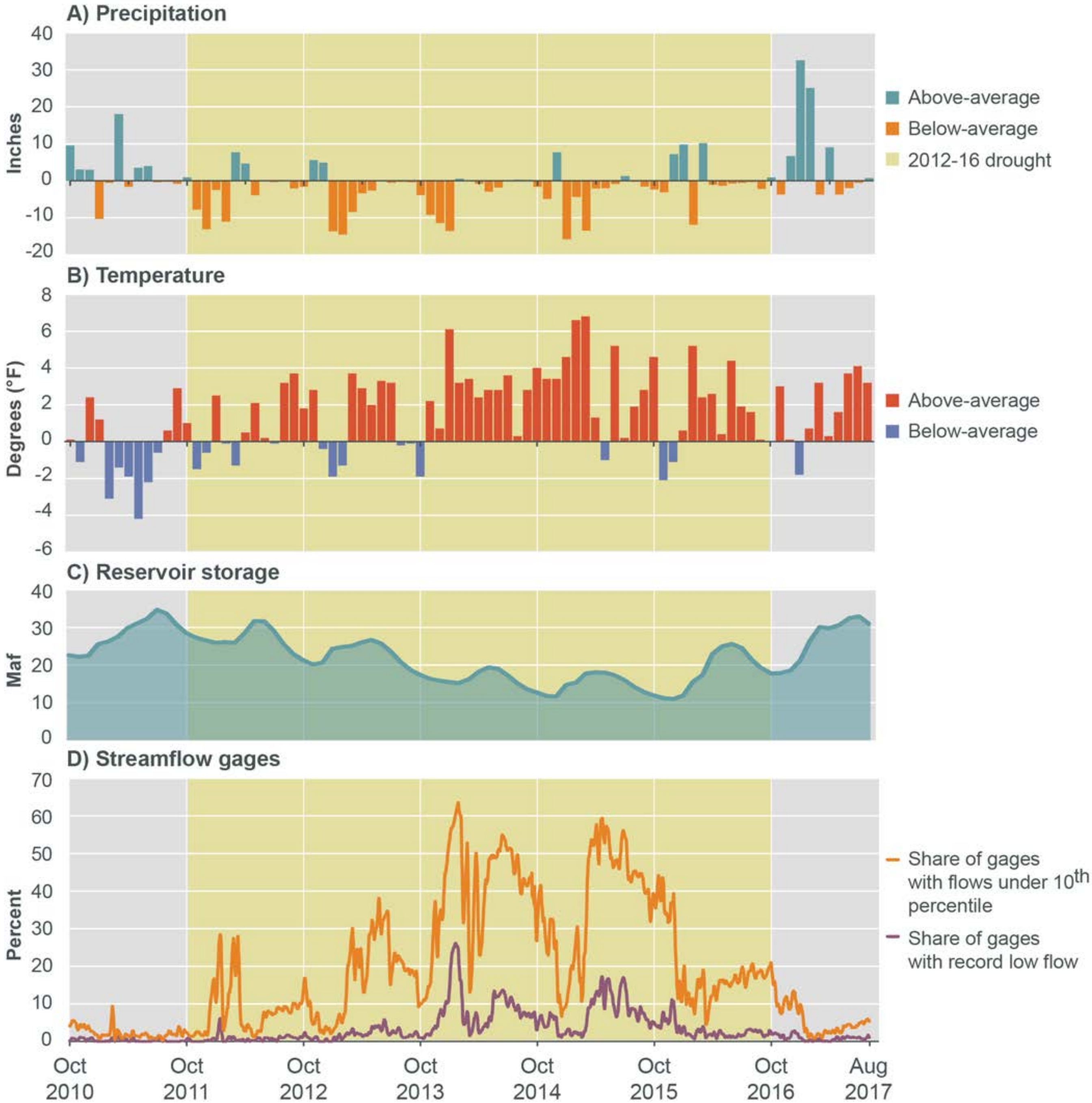

SOURCES: Western Regional Climate Center (precipitation) and National Oceanic and Atmospheric Administration (temperature).

NOTES: Bars in the top panel show the number of inches above and below the 1981–2000 annual average of 23.8 inches, based on water years (October–September). For 2017, August and September are assumed equal to 2016 values. The bottom panel shows degrees above or below the average statewide temperature for 1981–2000 (58.3° F). The 2017 value is an estimate—based on the average monthly temperature of January to August 2017, departing from the average temperature for the same months in the 1981–2000 period (59.5° F).

These unusually warm and dry conditions had severe consequences for California's freshwater ecosystems. The factors with the greatest impact are summarized in Figure 2. Prior to the drought, the state's reservoirs were full due to an exceptionally wet and cool winter and spring 2011. This played an important role in water management during the drought. During the first few years, water released from reservoirs was used to make up a portion of the shortfall due to reduced precipitation. But as shown in Figure 2C, by water year 2014 carryover storage in the reservoirs was small, leading to significant reductions in water deliveries and tensions over meeting flow and water quality requirements.

Rivers and streams throughout California had some of their lowest flows on record during the later stages of the drought (Figure 2D). Reduced winter flows in rain-fed streams—as well as diminished spring snowmelt flows in rivers fed by high elevation watersheds—contributed to the problem. Low precipitation also reduced groundwater recharge, which is the primary source of flow during summer and early fall on most rivers and streams. Thus, extreme low flows were common during the warmest times of the year, when ecosystems were most stressed.

**FIGURE 2**
Seasonal changes in precipitation, temperature, reservoir storage, and streamflows before, during, and after the 2012–16 drought




SOURCES: **Precipitation**: Department of Water Resources; **Reservoir storage**: California Data Exchange Center; **Temperature**: National Oceanic and Atmospheric Administration (NOAA) Climate at a Glance; **Streamflow gages**: United States Geologic Survey (USGS) Water Watch.

NOTES: The figure shows seasonal changes in water supply indicators for seven water years, 2011 to 2017. Water years run from October 1 to September 30. Values for 2017 end in August. Precipitation is the sum of San Joaquin 5-Station and Northern Sierra 8-Station monthly indices, departing from the 1981–2000 average; this measure accounts for most rainfall available for reservoir storage. Temperature is the monthly statewide temperature departure from the 1981–2000 average. Reservoir storage is the sum of monthly storage in 154 major reservoirs within the state (excluding storage in the Colorado River Basin). Streamflow gages are centered rolling seven-day averages of the shares of streamflow gages measuring record low flow or under 10th percentile flow in California's rivers and streams. Maf stands for million acre-feet.

Low flows—particularly when combined with record high temperatures—produced water quality concerns on rivers throughout the state. The warm, low flows contributed to the occurrence of toxic algae blooms in some rivers and reservoirs and parts of the Delta, and to low levels of dissolved oxygen on many salmon and steelhead rivers. Conditions were especially difficult for many species in 2014 and 2015, when the cumulative effects of water scarcity and high temperatures were at their peak.

As dramatic as the drought was, its ending was equally so. Water year 2017 was an unusually wet year, with record precipitation in many Northern California watersheds and two federal disaster declarations for flooding emergencies (including the Oroville Dam crisis). Atmospheric rivers impacted the state for more than 52 days.[5] All major reservoirs recovered to 2011 levels and rivers throughout the state ran at well above average flows.

The 2012–16 drought was unprecedented, but is also part of a longer period of warm and dry conditions. Since 2000, only six years have had above average levels of precipitation statewide, making this the driest 16-year period since record-keeping began in the 1890s. Following a warming trend that began in the 1980s, this is also the warmest 16-year period. Current climate projections suggest that the warm temperatures and low snowpack of this drought—along with very wet intervening years—will become more common as the global climate warms (Diffenbaugh et al. 2015).

Without improvements in water management and habitat, the prognosis for California's freshwater ecosystems is bleak, particularly for temperature-sensitive native fishes. A recent climate vulnerability assessment of California's native fishes found that business-as-usual approaches to environmental management will lead to population declines, driving many fish species to extinction by the end of this century. This includes three-quarters of the state's native salmon, steelhead, and trout species (Moyle et al. 2013, 2017). Other freshwater-dependent species, including amphibians and migratory waterbirds, are also at risk with current drought management approaches (Gardali et al. 2012, California Department of Fish and Wildlife 2016).

## How Institutions Responded

The record dry and warm conditions of 2012–16 tested the drought preparedness of federal, state, and local institutions (Hanak et al. 2015). Ecosystem management was difficult, controversial, and uneven across many watersheds (Mount et al. 2015).[6] Here we briefly review the legal context for managing water for ecosystems, along with some of the key tools the state used to allocate scarce surface water supplies during the drought. We then provide an overview of ecosystem management during the drought in eight case study areas.

### Managing Environmental Water during Drought: the Legal Context

A suite of state and federal laws—many enacted in the late 1960s and early 1970s—govern the allocation of water for the environment (Box 1). In many of California's regulated river systems—i.e., those that have large upstream reservoirs—these laws and implementing rules set minimum water quality and flow standards, which determine the volume and timing of water that must be bypassed or released from the reservoirs to support freshwater species and other environmental benefits (e.g., recreation).[7] Often, the focus of these flow requirements is on protecting one or more freshwater species listed as threatened or endangered under state and federal Endangered

[5] Atmospheric rivers are narrow plumes of moisture that resemble a river when viewed from space. These account for roughly half of the state's annual precipitation and are the cause of most winter floods. Satellite imagery from 1998 to present shows the number of atmospheric rivers in 2017 to be roughly double the average and a record for the period.

[6] During the drought, California Department of Fish and Wildlife (CDFW) set up a website that tracked activity by the agency and its partners. This included a description of actions, such as restoration projects, rescue activities, and extensive reporting on monitoring activities throughout the drought.

[7] California has more than 1,400 surface water reservoirs, created by more than 1,500 dams, which impound the waters of most major rivers and many smaller ones (Escriva-Bou et al. 2017, Lund et al 2016).

Species Acts (ESA). Some rivers and many ecologically sensitive streams do not yet have minimum flow standards, although environmental protection laws still apply there.[8]

Environmental laws can help reduce drought-related harm to ecosystems, both before and during droughts. However, when California cycles into a period of severe and sustained drought—as experienced from 2012 to 2016—these protections are sometimes relaxed, given the understandable desire to stretch supplies as far as possible to serve competing demands. In addition, in rivers and streams without minimum flow standards, it is difficult for the state to require water to remain in streams to protect aquatic species.

## Box 1: State and Federal Laws Important to Freshwater Ecosystem Management

California and the federal government have enacted a suite of laws that protect water quality, ecosystems, and fish and wildlife (Gray and Doolan 2016).These laws generally function by constraining the exercise of water rights or the discharge of pollutants to protect a specific aspect of the environment.

The most important include:

**California Porter-Cologne Act and Federal Clean Water Act**
These statutes require the State Water Board and the Regional Water Quality Control Boards to develop water quality control plans for the state's principal river basins. The plans define water quality objectives and protect various uses, including fish and wildlife. To implement the plans the boards can limit discharges of pollutants, and the State Water Board can place conditions on the storage and diversion of water by water-right holders.

**Section 5937 of the California Fish and Game Code**
This statute requires dam operators to release sufficient water to keep fish below the dam in good condition. This is a clear (but often ignored) legislative directive to release enough water to support healthy fish populations, not just to avoid jeopardy of extinction.

**Public Trust Doctrine**
This doctrine protects the public's rights in navigable waters and their submerged lands. Traditionally, this included navigation, commerce, and fishing, but it was later expanded to include recreational uses, water quality, and protection of ecosystems. Water-right holders and water managers must protect public trust values, which can include protecting instream flows and water quality for fish and wildlife.

**California and Federal Endangered Species Acts**
The state and federal Endangered Species Acts (ESA) prohibit the "taking"—or harming— of species determined to be at imminent risk of extinction (i.e., listed as threatened or endangered) without a permit. Federal agencies are required to consult with the US Fish and Wildlife Service or the National Marine Fisheries Service to ensure that their actions do not jeopardize the continued existence of listed species or adversely modify their critical habitat.

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[8] The Regional Water Quality Control Boards have authority to set and enforce water quality standards on most waterways. An exception is the Sacramento–San Joaquin Delta, where the State Water Board has principal water quality authority. Relatively few waterways have minimum instream flow standards to protect public trust values, such as native fish. At the time of this writing, the State Water Board is in the process of setting minimum flow requirements for the principal tributaries of the Sacramento and San Joaquin Rivers. It also is studying ways to set instream flow standards on waterways throughout California. Working with university and non-governmental organization scientists, they are attempting to develop analytical methods to rapidly define minimum instream flow needs. The concept of "functional flows," discussed later in this report, is guiding the development of minimum instream flow standards.

One of the state's main legal tools for relaxing environmental standards was through Temporary Urgency Change Orders. During severe water shortages, the State Water Board will consider Temporary Urgency Change Petitions (TUCP) from water-right holders that seek to relax water quality standards. From 2014 to 2016, the board issued numerous change orders.[9] As described in our case studies for the Sacramento–San Joaquin Delta and the Yuba River, these orders allowed water managers to better allocate scarce supplies for competing ecological uses across the year, but also avoided further reducing water supplies for agricultural and urban users.

The board's other key legal tool for managing scarce surface water supplies during this drought was the curtailment of water rights. Initially, these curtailments suspended the ability of more junior water-right holders to divert water from rivers.[10] As shortages became more pronounced, more senior rights—including riparian water rights—were affected in watersheds throughout Northern California. However, because environmental uses are seldom embodied in water rights, they generally were not considered in this process.[11] The exceptions were several small tributaries to the Sacramento River and efforts to protect coho salmon and steelhead in the Russian River, both examined in our case studies.

## Case Studies in Drought Management

We selected eight case studies to highlight the range of challenges faced by those charged with managing freshwater ecosystems as the 2012–16 drought wore on. (For details, see the Technical Appendix).[12] These case studies draw on publicly available information, as well as interviews with water managers, stakeholders, and state and federal regulators. They fall into three broad categories: regulated waterways (i.e., those with dams), unregulated waterways, and managed wetlands.

### Regulated Waterways

Flows in many waterways in California are regulated by upstream surface reservoirs. These reservoirs increase flexibility to manage flows for ecosystems during drought. However, during multi-year droughts, storage is severely reduced. By the third year of the 2012–16 drought, most reservoirs were at or near record low levels, which reduced operating flexibility to accommodate competing demands (Figure 2C, Mount et al. 2015, Hanak et al. 2015). Within the Sacramento and San Joaquin River regions, these reservoirs not only served local water demands, they were also essential for meeting flow and water quality needs downstream, including outflows from the Sacramento–San Joaquin Delta to maintain low Delta salinities. Where reservoirs blocked access to upstream salmon spawning and rearing habitat, they held the only source of cold water available for these temperature-sensitive fishes, placing added constraints on reservoir operators.

Table 2 summarizes how these issues were handled on four regulated salmon and steelhead-bearing rivers: (1) the Trinity River, the Klamath River's largest tributary and a source of water for the CVP; (2) the Sacramento River operations at Shasta Dam, the CVP's largest reservoir and cold water source for winter-run Chinook salmon; (3) the Yuba River, the main supply for irrigators in Yuba County; and (4) Putah Creek, which supplies water for urban and agricultural uses in Solano County. In addition, we examined the complex array of actions to maintain water quality within the Sacramento–San Joaquin Delta for CVP and SWP exports and in-Delta uses, and fish

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[9] For a summary through summer 2015, see technical appendix Table A1 and related discussion in Hanak et al. (2015).

[10] The State Water Board's curtailment website contains a complete list of curtailment actions. In California's priority based water rights system, those who obtained water rights later are the first to be cut during drought. Senior appropriators and riparians are the last to be curtailed.

[11] California recognizes a few instream water rights under Water Code §1707, but these rights do not play a significant role within their respective watersheds. California's general failure to integrate environmental water uses into its water rights curtailment process stands in marked contrast with the approach in Victoria, Australia. In Victoria's system, all water rights or "entitlements" (including environmental entitlements) are subject to reduction during drought, and curtailment may be initiated to protect environmental watering objectives (Mount et al. 2016a).

[12] To date, there has not been a comprehensive synthesis of the institutional actions to mitigate the drought's environmental impacts, and no assessment of their effectiveness. Our case study approach aims to tease out key insights by comparing responses in different types of ecologically important, drought-impacted watersheds.

during the drought. All of these areas have some form of explicit environmental water requirements. The case studies document a spectrum of drought vulnerabilities and responses, ranging from relatively robust management systems for Putah Creek and the Yuba River, to extreme management weaknesses in managing cold water for salmon at Shasta Reservoir.

### Unregulated Waterways

Unregulated rivers and streams lack infrastructure to store and release significant volumes of water. This makes them more difficult to manage during drought, and more susceptible to effects from diversions by water users. Flows and water quality in many of these systems declined significantly with the record low flows and high temperatures in the summers of 2014 and 2015. Surface water diversions, along with lowered groundwater tables (a result of increased pumping and less natural recharge), reduced flows in many of these rivers.[13] Lacking surface storage, managers wishing to reduce impacts on ecosystems had only one option: managing agricultural and residential water demand. We explored efforts to conserve salmon and steelhead in Deer, Mill, and Antelope Creeks—tributaries to the Sacramento River—as well as the unregulated tributaries of the Russian River (Table 3). These were the two cases where the State Water Board and its agency partners (especially the California Department of Fish and Wildlife) used the curtailment process and related actions to support ecosystems. The efforts underscored the challenges of implementing effective actions in areas that lacked clear requirements regarding environmental flows, and good information about water availability and use and ecosystem conditions.

### Managed Wetlands

Permanent and seasonal managed wetlands—where water is intentionally applied to create habitat—are essential to resident and migratory waterbirds in California along with other wetland-dependent species like the endangered giant garter snake. During drought, federal, state, and private wetland managers often see significant reductions in available water needed to sustain this habitat on dedicated refuge lands. In addition, drought reduces seasonal flooded habitat created by farming practices—especially in rice fields. Given its importance to the Pacific Flyway, we focused on management of refuge water and fall and winter rice flooding in the Central Valley (Table 4). Refuge management was facilitated by the availability of a designated water supply, established under the Central Valley Project Improvement Act (CVPIA), a federal law enacted in 1992.

[13] One of the largest impacts on unregulated rivers during the drought was dewatering by illegal marijuana growing operations, particularly in the North Coast region. These withdrawals caused significant harm, limiting flows in streams already stressed by low rainfall. The State Water Board—along with the Department of Fish and Wildlife—conducted multiple enforcement actions against growers starting in 2015. Some of these efforts are described on CDFW's drought page.

**TABLE 2**

Freshwater ecosystem management on regulated rivers during the 2012–16 drought: summary of case studies

| Case study | Summary of drought conditions and actions | Key takeaways |
|---|---|---|
| Trinity River | • In 2000 the Trinity River Restoration Program (TRRP) set aside more water for fish to reduce die-offs on the Klamath River below the confluence.<br>• During this drought the US Bureau of Reclamation (USBR) tried to time releases to improve flows and quality on the Klamath River. | • The TRRP brought together parties to set objectives before the drought.<br>• USBR's initial delays in releasing water for fish led the fisheries to the brink.<br>• Emergency releases likely prevented massive fish die-offs under extreme conditions. |
| Shasta Dam (Sacramento River) | • Shasta Reservoir is the sole source of cold water for winter-run Chinook salmon.<br>• The reservoir is critical to maintaining water quality in the Delta for water users and fish.<br>• Drought conditions, technological issues, and poor management decisions resulted in high-temperature releases from Shasta Dam, leading to two consecutive brood year collapses of winter-run Chinook salmon. | • Failure to update water quality monitoring contributed to warm water releases.<br>• Lack of transparency and cooperation among federal and state agencies were not resolved until late in the drought.<br>• Drought preparation and scenario testing would have revealed weaknesses in management.<br>• Managers were unable to balance water demands with needs of salmon. |
| Yuba River | • The 2008 Yuba River Accord (YRA) created an integrated system of surface and groundwater management that improved ecosystem conditions and reduced the conflicts over supplies for local irrigators and downstream users.<br>• Conditions had to be adjusted in 2014 through a TUCP to protect against Bullards Bar reaching minimum pool, which would have had adverse effects on fisheries. February rainfall was high enough that the TUCP was never implemented. | • The YRA sets flow targets across a range of hydrologic conditions. This planning better protects the environment and provides more certainty for water users.<br>• The YRA accounting systems are trusted by water users and other stakeholders.<br>• Groundwater recharge boosts dry year supplies.<br>• Environmental flows can be transferred to downstream users, generating revenues and mitigating water shortages downstream. |
| Putah Creek | • A 2000 settlement agreement set up a management plan that created a flow regime to support native species, and engaged water users and stakeholders.<br>• Lake Berryessa did not get low enough for drought measures to be enacted. | • The flow regime matches native fish adaptations, increasing resilience to droughts.<br>• Negotiated flows kept water costs reasonable and reduced uncertainty.<br>• A Stream Keeper leads restoration and adaptive management efforts and serves as a focal point for community and water user engagement. |
| Sacramento– San Joaquin Delta | • In 2014 and 2015 insufficient water was available in CVP and SWP storage for water quality and regulatory outflows in the Delta.<br>• In 2014 and 2015 state and federal water-right holders petitioned the State Water Board to relax water quality and flow requirements to conserve water in storage.<br>• The board temporarily allowed lower outflows and higher salinity in the Delta and construction of temporary salinity barriers. It also limited pumping when health and safety standards were not met. | • The timing of TUCPs reflected insufficient pre-drought planning and priority-setting.<br>• Pre-drought scenario testing of actions could have streamlined decision making.<br>• Outflow required for ecosystem protection was the focus of debate. Weak accounting systems exacerbated conflicts and reduced flexibility.<br>• Population levels of some fishes reached historic lows in response to conditions in the Delta. |

SOURCE: Technical Appendix.

**TABLE 3**

Freshwater ecosystem management on unregulated rivers during the 2012–16 drought: summary of case studies

| Case study | Summary of drought conditions and actions | Key takeaways |
|---|---|---|
| Deer, Mill, and Antelope Creeks (Sacramento River tributaries) | • Record low flows in 2014 prompted the State Water Board to declare emergency regulations to protect stream flows.<br>• Minimum flows and pulse flows were set, along with options for voluntary agreements to reduce diversions (and authority to curtail if agreements weren't reached) for all three creeks.<br>• In 2015 the emergency regulation was renewed, but an insufficient number of water-right holders participated in voluntary reductions, resulting in two curtailment orders for Antelope Creek. | • Parties had ample data and a good grasp of the biology and hydrology of Deer, Mill, and Antelope Creeks prior to the drought.<br>• On Mill Creek, plans and strategies adopted before the drought eased implementation of the emergency drought regulation.<br>• The board's actions likely avoided catastrophic dewatering, but it is unclear how the increased flows helped overall salmon and steelhead populations. |
| Russian River tributaries | • There was potential for a major loss of threatened and endangered fish species in many nearly dewatered tributaries, where juvenile fish were trapped.<br>• Some voluntary measures were implemented by wineries to boost flows. Emergency regulations in 2015 limited surface water diversions and groundwater pumping for some domestic uses. | • State and federal agencies lacked data about water use and had difficulty enforcing water conservation rules in a rural setting.<br>• Data collection started late in the drought, and the amount of water conserved is unknown.<br>• Voluntary actions helped fish move out of some low-water areas.<br>• Lack of advanced planning and information gathering hampered the effectiveness of efforts to gather information and protect target species. |

SOURCE: Technical Appendix.

**TABLE 4**

Wildlife refuge and wetland management during the 2012–16 drought: summary of case study

| Case study | Summary of drought conditions and actions | Key takeaways |
|---|---|---|
| Managed wetlands (Central Valley) | • The 1992 CVPIA established targets for delivery of water to the refuges, generally improving the reliability of supplies.<br>• Water deliveries to the refuges were reduced to as little as 48% of the CVPIA targets at the height of the drought, on par with cuts to senior CVP contractors.<br>• Declines in irrigation water also reduced rice acreage, which serves as waterbird habitat, particularly during fall.<br>• There was concern that birds would suffer, as food resources were exhausted and reduced habitat could make birds vulnerable to disease outbreaks. | • Although availability of refuge water was essential, late announcements of deliveries reduced watering opportunities.<br>• A diverse group of stakeholders worked together to ensure that the limited available water was put to the best use. Where cooperation was emphasized, the resource was more effectively managed.<br>• Official bird monitoring data was too infrequent to facilitate real-time management, but some alternatives, such as citizen scientist bird tracking, helped. Progress is also occurring on monitoring bird habitat.<br>• Reverse auctions helped augment habitat on working lands. Facilitating water transfers between refuges and with other water agencies would give managers more flexibility to stretch supplies. |

SOURCE: Technical Appendix.

## Three Key Lessons from the Drought

The eight case studies illustrate both strengths and weaknesses in how California prepares for and responds to drought effects on freshwater ecosystems. Weaknesses—apparent in some of these cases—both put ecosystems and native biodiversity at risk, and heightened conflict over competing water uses. Three key lessons emerge:

**Better accounting for the environment.** Water management during the drought would have benefitted from a more modern water accounting infrastructure (Mount et al. 2015, Hanak et al. 2015, Escriva-Bou et al. 2016). In watersheds where baseline water use or flow information was either unavailable or of limited value, or where accounting standards were not transparent and agreed upon, management effectiveness suffered and conflict was heightened. Problems were compounded in many watersheds by sparse information about ecological conditions and target species. Where this information was available, it streamlined and improved decision making, but where absent, it delayed decision making and made it difficult to justify allocation of water to ecosystems.

**Better drought planning and preparation.** Watersheds where investments were made to plan and prepare for drought—and the difficult water allocation decisions that arise from it—experienced less conflict and were better able to mitigate harm to ecosystems. But in most cases, improved planning tools that prescribed actions and priorities before, during, and after drought—coupled with pre-drought investments in habitat—would have protected freshwater ecosystems more effectively. Many watersheds were plagued by ad hoc decision making because of a lack of sufficient preparation for ecosystem impacts of drought. This slowed responses, reduced effectiveness of actions, and heightened tensions.

**Flexibly managed ecosystem water budgets.** Ultimately, managers also needed water to support ecosystems, and the ability to adapt to conditions as they unfolded. The drought made it necessary for all sectors to operate with reduced supplies, and in some cases rigid environmental flow rules and complex approval systems inhibited adaptation. But management functioned best where there were well defined water allocations for ecosystems. Rather than relying on unevenly applied minimum flow standards, environmental managers would have benefitted from a defined quantity of water they could manage flexibly, store, and trade. Such ecosystem water budgets would also have helped water users by reducing regulatory uncertainty over water allocated to ecosystem uses within watersheds.

In the following pages, we describe these policy reforms and the roles and responsibilities of key state, federal, and local stakeholders that will be instrumental to their success (Table 5). Subsequent sections briefly outline legal and funding issues central to a successful reform package.

**TABLE 5**

A plan of action for improving drought management in freshwater ecosystems

| Area of reform | Action needed | Key actors |
|---|---|---|
| Improve accounting for the environment | Strengthen water accounting infrastructure | **State**: DWR, State Water Board, California Legislature<br>**Federal:** US Geological Survey, US Bureau of Reclamation (USBR)<br>**Local:** regional and local water agencies |
| | Develop more timely and transparent estimates of environmental water use | **State:** DWR and State Water Board |
| | Improve monitoring of ecosystem conditions | **State:** CDFW, Delta Science Program, DWR (SWP)<br>**Federal:** US Fish and Wildlife Service (USFWS), National Marine Fisheries Service (NMFS), USBR (CVP)<br>**Local:** regional and local water agencies, environmental organizations, tribes, universities, and other scientific institutions |
| Strengthen drought planning and preparation | Prepare and implement watershed ecosystem plans that address drought | **State:** CDFW, State Water Board, DWR (SWP)<br>**Federal:** USFWS, NMFS, USBR (CVP)<br>**Local:** regional and local water agencies and users, environmental organizations, tribes, and other watershed stakeholders |
| | Develop annual watering plans | |
| Establish ecosystem water budgets | Define EWBs as an integrated component of the water rights system | **State:** State Water Board, California Legislature, CDFW, DWR (SWP)<br>**Federal:** USFWS, NMFS, USBR (CVP)<br>**Local:** regional and local water agencies and users, environmental organizations, tribes, and other watershed stakeholders |
| | Create a management structure for EWBs | |
| | Grant EWBs management flexibility | **State:** State Water Board, California Legislature |
| | Increase certainty in the allocation and management of environmental water | **State:** CDFW, State Water Board<br>**Federal:** USFWS, NMFS, Federal Energy Regulatory Commission (FERC) |

NOTES: The key actors column lists entities that will be instrumental to the successful implementation of the recommended actions. We recognize that other entities will also play important roles.

## Improve Accounting for the Environment

Weak water accounting and monitoring systems make it difficult to manage water for the environment, and unnecessarily increase tensions over the use of water to meet ecological goals. Managing scarce water well requires reliable measurement and modeling systems informed by good understanding of ecosystem conditions and the likely response of those ecosystems to management actions. It is also vital that the water user and stakeholder communities have a clear understanding of how water is used to improve ecosystem performance and whether allocations were used efficiently and created positive results.

Our case studies show the value of high quality water measurement and information systems, as well as the consequences of low quality systems. Where investments were made to understand and closely manage water availability and use, uncertainty over the quality of information was low and did not significantly affect decision making. Additionally, where investments were made in assessing and monitoring ecosystem conditions, there was better understanding of the rationale behind environmental water allocations. The Yuba River, Putah Creek, and Mill, Deer, and Antelope Creeks are useful examples of the benefits of up-front investments in information systems. In most other cases, the lack of information—and poor public understanding of this information—hampered decision making and increased controversy.

Limited water accounting and environmental monitoring was a major impediment to management on unregulated rivers and streams. One case in point is the tributaries of the Russian River. In 2015, the State Water Board issued emergency orders to more than 10,000 landowners, instructing them to reduce their domestic water use—principally groundwater—to protect related surface water flows for endangered coho salmon. The board also required landowners to submit information on their surface water diversions, groundwater pumping, and domestic use. But the lack of any historical water accounting information made it impossible for the board and CDFW—its partner in this effort—to determine if the information was accurate enough to guide management. The absence of long term data on fish presence and other ecological conditions on these tributaries also precluded determination of whether the emergency water use restriction met its primary objective of improving flows to support the survival of coho salmon. And on other unregulated rivers and streams, the data gaps were generally so severe that they made it difficult for CDFW and the board to take and justify any actions to improve environmental flows during the drought.

Information challenges and controversy were also a factor on some of the state's largest regulated river systems. One of the more publicized failures to manage endangered species during the drought occurred on the Sacramento River below Shasta Dam. Although there was adequate environmental monitoring downstream of Shasta Dam, USBR and its consultants relied on obsolete measuring and modeling tools to manage cold water reserves within Shasta Reservoir. In summer 2014, and again in 2015, USBR released warm water into the Sacramento River, killing more than 95 percent of endangered winter-run Chinook salmon eggs and fry, pushing this fish close to extinction in the wild.

More generally, weak water accounting and ecological monitoring systems also hampered the State Water Board's efforts to evaluate TUCPs and to administer water-right curtailments. For the TUCPs, it was difficult to forecast the water supply and the environmental consequences of relaxing water quality standards. This proved critical to managing Delta outflows and salinities. The board also struggled to implement curtailments due to large uncertainties over the volumes of water diverted by water-right holders and returned to rivers from irrigated fields. Although curtailments were not widely used to protect ecosystem flows this time, improvements in these indicators will be necessary to make it possible in future droughts.

Finally, confusion over the actual volumes of water allocated to the environment during the drought contributed to misinformed and contentious public debate. The official state water accounts—developed by DWR and included in periodic updates of the California Water Plan—were out of date, with the latest available numbers for 2010 (California Department of Water Resources 2013). Moreover, these accounts do not provide transparent estimates of environmental water (Gartrell et al. 2017). Some stakeholders used DWR's estimate that the environment uses roughly half of all water on average statewide to make the case that regulations to support ESA-protected fishes were the cause of water scarcity during the drought. This failed to recognize several key facts about environmental water. First, most of this water is flows on North Coast "wild and scenic" rivers that do not compete with other water uses. Second, the environmental water share is much smaller during droughts, when surface supplies are low. And third, a large portion of environmental water in some places—particularly the Delta—is used to maintain water quality for agricultural and urban uses of water, not just for protected species.

## Recommended Reforms

We recommend three areas for accounting reform: strengthening the state's water accounting infrastructure, developing more timely and transparent estimates of environmental water use, and improving monitoring of ecological conditions to better inform management decisions and improve public understanding of the purposes and benefits of environmental water allocations.

### 1. Improve Water Accounting Infrastructure

A recent PPIC review of California's water accounting infrastructure identified significant modernization needs (Escriva-Bou et al. 2016).[14] Issues include a lack of a common statewide accounting framework; outdated technology to measure water availability and use; poor documentation of water rights and their associated terms and conditions; limited standards for water accounting and reporting; and the need for better water information systems to guide managers, regulators, policymakers, and stakeholders. These weaknesses made it more difficult to manage water effectively during the drought. California has made some progress on improving its water accounting and reporting requirements.[15] But much more work will be needed, particularly to firm up information critical to environmental water management. Priorities include:

- **Improving understanding of surface water availability and use.** Rivers and streams provide essential habitat for freshwater ecosystems, and are the primary sources of water for the environment. But California lacks stream gages on half of the rivers and streams that support critical habitats. And more generally, surface water monitoring systems need strengthening and consolidating. Major advances in technology exist that could be used to allow for real-time monitoring and projections of conditions. Developing new ways to communicate information to increase transparency for all water users will also be key (McCann and Escriva-Bou 2017).
- **Defining and documenting water rights and resolving water-right claims.** This is important for improving the understanding of tradeoffs between the allocation of water for the environment and other uses, and making more flexible management possible. The State Water Board's efforts to manage curtailments of water rights also would have benefitted from such improvements.
- **Improving estimates of net water use and return flows.** Understanding the net amount of water that water-right holders use—not just the amount they divert—is critical for environmental management.[16] On some rivers in agricultural areas, such as the lower San Joaquin River, most flow is "return flows" of water not consumed by crops in irrigated fields. Similarly, many small streams in urban areas derive flow from wastewater treatment plants. These flows need to be documented and accounted for.
- **Accounting for groundwater use and recharge.** Summer and early fall base flow in many unregulated rivers comes from groundwater discharge through springs and the beds of rivers. More information on the groundwater contributions to these rivers—and the role water use plays in depleting streamflow—is critical to managing water for ecosystems during droughts.

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[14] This study evaluated the state of California's water accounting infrastructure and compared it to systems used by 11 other western states, Australian, and Spain.

[15] A package of water bills enacted in 2009 increased reporting requirements for surface water diversions and groundwater levels. Since the onset of the latest drought, Senate Bill 88 (2014) strengthens surface water diversion reporting and measurement requirements and Assembly Bill 1755 (2015) requires the state to improve online data input and availability. The 2014 Sustainable Groundwater Management Act requires much more reporting of groundwater use. During the drought, the State Water Board issued orders requiring water users to provide more timely, and in some cases additional information. This was most significant in emergency orders in the Russian River tributaries.

[16] Water right permits and licenses define the rate and total amount of water that can be diverted, the time and place of diversion, and the place of use; they do not mention the amount or location of water returned to the system in the form of surface runoff, drainage from irrigated lands, groundwater percolation, treated wastewater, etc. As a result, the water right always overstates the net—or "consumptive" —use by the water-right holder. Although California has been improving the reporting and measurement of surface water diversions, the state is further behind on estimating net water use and return flows to rivers, streams, and aquifers.

Accounting for water use and availability involves a wide range of entities at the federal, state, and local levels, all of which will need to be involved in strengthening water accounting infrastructure (Escriva-Bou et al. 2016, Table 5). Two state agencies—DWR and the State Water Board—must take the lead in promoting a more coherent, comprehensive statewide system.

## 2. Develop More Timely and Transparent Estimates of Environmental Water Use

California also needs more timely, transparent, and detailed accounting of environmental water use. This will aid decision making by increasing understanding of issues and tradeoffs, and creating a common body of knowledge to inform policy debates.

As detailed in the companion report by Gartrell et al. (2017), we propose using accounting categories that more accurately reflect the different uses of water within a watershed:[17]

- **Water diversions.** Water reserved for diversion by water-right holders. The State Water Board and the courts supervise the use of this water.
- **System water.** Water required to support these diversions.[18] For example, some water must remain in rivers to offset seepage losses into groundwater basins through the river bed or losses due to evaporation. And in some rivers, a portion of the flow is needed to maintain water quality sufficient for diversions. Water that needs to remain in rivers to cover conveyance losses is regulated under the water rights system, and water quality related flows are set forth in water quality control plans established by the State Water Board and its network of regional boards.
- **Ecosystem water.** Water required to support fish and wildlife. These flows are primarily determined under the federal Clean Water Act and Endangered Species Act (ESA) and its state law counterparts, and administered by the State Water Board and federal and state fish and wildlife agencies (Box 1).
- **Uncaptured water.** Water in excess of the three preceding categories. During most years and on most rivers—even during droughts—there are periods when river flows exceed either the capacity of existing storage and diversion facilities or the combined demands for water diversions, system water, and ecosystem water. While some of this water is available under existing water rights (e.g., when water users have valid claims to the water but do not have the capacity to divert it because of infrastructure constraints), much of it constitutes flood flows that are not currently claimed under the water rights system.

Although these different categories of flows can provide multiple, overlapping benefits, it is important to distinguish among them in water accounts. To avoid double- or triple-counting the volume of water put to use within the system, we propose a hierarchy of accounting that follows the order of water uses listed above: water diversions, system water, ecosystem water, and uncaptured water. In this approach, water assigned to the ecosystem is limited to the *incremental* or *net* volume of flows needed to meet regulatory requirements, in excess of water for diversions and system water. This does not diminish the role water diversions or system water can serve in meeting ecosystem regulatory requirements, but it helps distinguish the cases where regulations lead to

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[17] This analysis focuses on surface water because it provides almost all environmental water use. In basin-wide water accounting exercises, it is also necessary to account for groundwater—a major source for agricultural and urban water diverters in some regions and years. Water balances also need to consider how groundwater and surface water interact—since rivers can be sources of groundwater recharge, and groundwater can augment river flows. Finally, water uses in any given period can be larger or smaller than the amount of water available from annual runoff because of changes in storage in surface reservoirs and aquifers. Surface reservoir releases are important for environmental water availability in California, and in some places—such as Yuba County—coordinated management of surface and groundwater storage contributes to environmental flows (see the Yuba River case study in the technical appendix to this report).

[18] We have borrowed the term "system water" from Victoria, Australia, where it is also known as "planned environmental water." For a description of environmental water use and allocation in Victoria, see Mount et al. (2016).

additional flow requirements. By definition, benefits provided by uncaptured water are above and beyond those required by environmental regulations for system and ecosystem water.

This classification differs from DWR's current environmental water accounting approach in two key ways. First, it makes an explicit distinction between regulatory requirements for system and ecosystem water. Second, it explicitly and systematically tracks uncaptured water—something not well done in DWR's current accounts.

The apportionment of water in the Sacramento–San Joaquin Delta highlights the utility of this change in water accounting (Box 2). A large and growing volume of environmental water that flows to the ocean is system water—required to protect the quality of diversions by Delta exporters and in-Delta water users. This water also provides ecosystem benefits, but it would be required even if there were no ecosystem management objectives in this region. Ecosystem water has also been increasing because of regulatory changes since the mid-1990s.

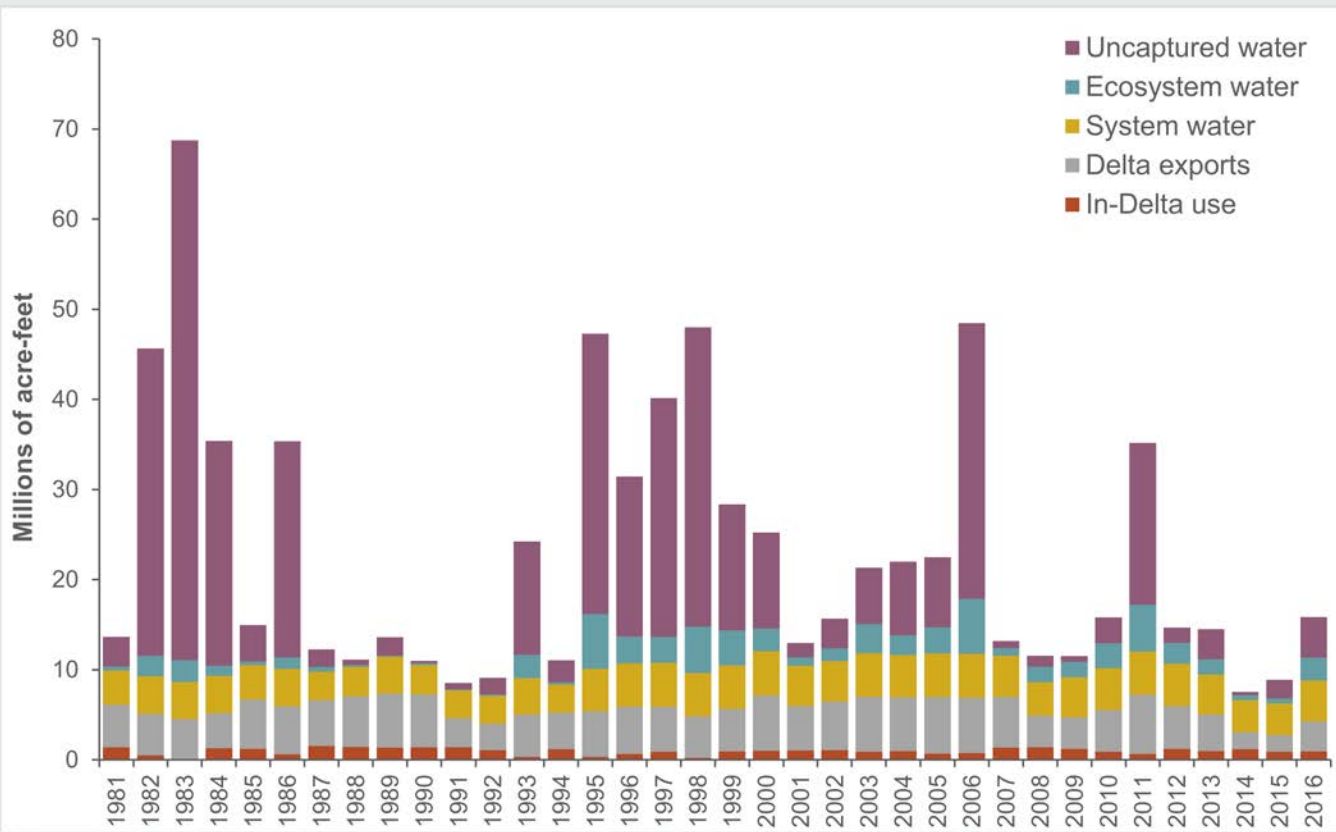
## Box 2: Accounting for Delta Outflow

Outflow of freshwater from the Sacramento–San Joaquin Delta mixes with saltwater of the San Francisco Bay, making it too salty for use by cities and farms. Some of this outflow is system water needed to keep salinity in the Delta low enough so that water can be exported by the CVP and SWP or used within the Delta. To meet water quality and flow standards for the health of the Delta ecosystem and its endangered fishes, regulations require an additional amount of "ecosystem water." This water comes from inflows to the Delta as well as limits on CVP and SWP pumping. And in most years—even during droughts—inflows to the Delta will exceed the capacity of water users to divert the additional water available in the system at some times. This "uncaptured water" makes up a large proportion of Delta outflow during wet years, and helps keep water quality high for all uses.

The amount of Delta inflow apportioned to system and ecosystem needs varies with hydrologic conditions, and has also changed over time with changing salinity conditions and ecosystem regulations (Figure 3). The volume of system and ecosystem water does not translate directly to a loss of water for exports. In wetter years, there is often sufficient water to meet water quality and flow requirements without reducing exports. To make up for export pumping restrictions in some months, exporters can often vary the timing of pumping. Ecosystem water is most likely to present a direct tradeoff with water exports during dry years, when there are fewer uncaptured flows. The increased use of export pumping limits for fish protection since the late 2000s has also increased the likelihood of tradeoffs in normal and wet years.

**FIGURE 3**

Where Delta water went



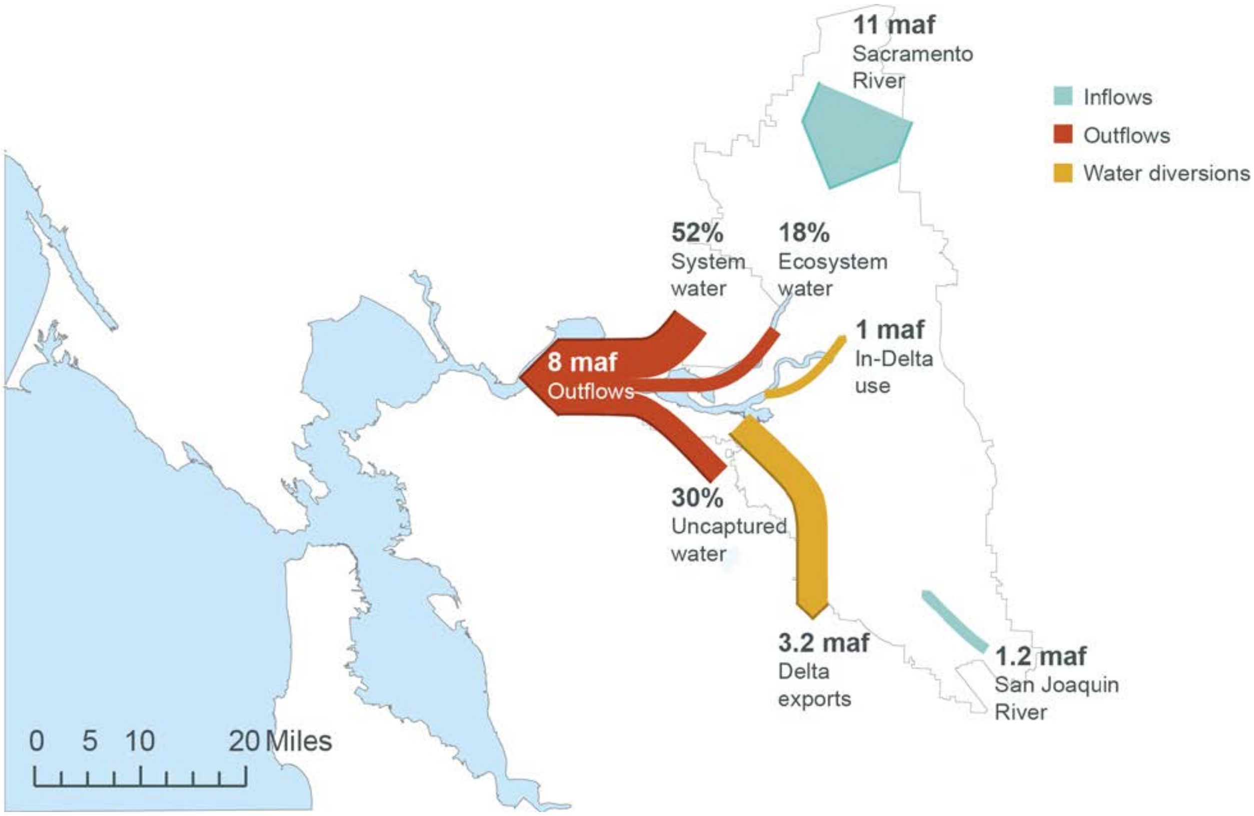

SOURCES: Gartrell et al 2017 (details are in the Technical Appendix and *PPIC Delta Water Accounting data*).

NOTES: Years shown are water years (October 1 to September 30). In-Delta use includes diversions by farms and in-Delta communities, the Contra Costa Water District, and the North Bay Aqueduct. The estimates of system, ecosystem, and uncaptured water are based on the State Water Board's Water Quality Control Plans and regulations under the Endangered Species Act and other relevant laws.

The separation of system and ecosystem water counters the claims that water to support endangered fish species dominated Delta outflow during the 2012–16 drought (Figure 4). Over the entire period, ecosystem water averaged 1.5 million acre-feet (maf) per year (19% of Delta outflow). Meanwhile, system water requirements to keep the Delta fresh enough for water users averaged 4.1 maf per year (51%)—a volume equivalent to total water diversions. In 2015, the worst year of the drought, ecosystem water played a very small role—accounting for 0.5 maf of Delta outflow (9%) versus more than 3.5 maf (57%) for system water needs.[19]

**FIGURE 4**

Ecosystem water was a small share of total outflows from the Delta during the 2012–16 drought




SOURCE: Gartrell et al. 2017.

NOTES: The figure shows the sources of inflows into the Delta and the distribution of that water during the 2012–16 water years (October 2011 through September 2016). In-Delta use includes diversions within the Delta and by Contra Costa Water District and the North Bay Aqueduct. The area within the boundary line is the legal Delta—the area where the Sacramento and San Joaquin Rivers converge, which is subject to tidal action.

Although the distinction between system water and ecosystem water may be most significant for the Delta—given the importance of salinity control for water diversions—we believe there is value in extending this accounting approach to other watersheds and regions. This means unpacking and quantifying the uses of water now classified in DWR's environmental water accounts as destined for wild and scenic rivers, instream flows, and wetlands, and providing consistent and transparent estimates of uncaptured water. [20]

[19] These estimates are for water years. The share of water assigned to the Delta ecosystem increases significantly during wetter years (Box 2).

[20] In upstream portions of watersheds, such as rivers upstream of the Delta, it will be especially important to distinguish between the volumes of environmental water consumed locally (net water use), and the volumes that flow further downstream and become available for reuse. DWR's current accounts are not

This new categorization enables a more accurate accounting of how water is used. It is a necessary step in documenting the benefits and costs of water quality and flow management, both for the water rights system and for ecological uses. It also reduces misunderstanding about the uses of environmental water. The Delta example presented here was conducted with limited staff resources and publicly available data and models. It shows that environmental water accounting can be done in a timely manner—essential for effective water management and for dispelling myths.

State agencies should take the lead on implementing this reform (Table 5). As the keeper of the official state water accounts, DWR has a major role to play, but it should work closely with the State Water Board, which oversees many of the rules and regulations governing the allocation of water to these different categories.

### 3. Improve Monitoring of Ecosystem Conditions

It is also essential that water accounting programs be supported by monitoring that provides information on the status of ecosystems—including target species and trajectories of change. Done well, monitoring programs guide management decisions and experiments, inform ecosystem models that can be used to test management actions, and measure the effectiveness of those actions. This is necessary to build confidence among the water user and stakeholder community that allocations of environmental water are used efficiently.

California invests extensively in monitoring that helps inform management decisions. Notable examples include the Southern California Coastal Water Research Project to monitor coastal streams, estuaries, and the ocean of the south coast; the Delta Science Program and the Interagency Ecological Program, which coordinate state and federal agency monitoring in the Delta and its watershed; and the San Francisco Estuary Institute's water quality and ecosystem monitoring program throughout the San Francisco Bay Area.

While these programs are useful—particularly when it comes to water quality monitoring—the drought revealed many gaps in understanding, both within the areas of interest of these large programs and, more generally, statewide within critical watersheds. The State Water Board, along with CDFW and federal fish and wildlife agencies, should conduct a comprehensive evaluation of the gaps in understanding and develop monitoring programs to cover these gaps. One of the goals of these plans should be to gather information that allows—as outlined in the next section—better preparation for severe drought.

## Strengthen Drought Planning and Preparation

California also needs a better blueprint for preparing for, responding to, and recovering from the ecological consequences of drought. Much like planning in the urban water sector—where agencies consider strategies for weathering multi-year droughts—ecosystem planning should incorporate drought contingency plans that evaluate the state of preparedness for droughts and the array of actions needed to mitigate drought effects.[21] This basic effort would likely have improved the speed of response and reduced some of the adverse ecological consequences of the 2012–16 drought.

We found several examples where pre-drought planning and preparation reaped dividends. Perhaps the best comes from the Yuba River Accord, where drought contingencies—including shifting farmers to groundwater

transparent in this regard. For instance, a large portion of flows in upstream segments of wild and scenic rivers in the Sacramento and San Joaquin Valleys is counted as net environmental water use, even though these river segments flow into reservoirs used for downstream water supply.

[21] Mitchell et al. (2017) describes how California's urban water planning structure supported the resilience of this sector during the latest drought.

reserves to leave water in the river—were negotiated in advance. On Putah Creek, negotiated agreements about drought actions as part of a 2000 settlement increased certainty and reduced conflict over potential allocations of water (although these proved unneeded due to sufficient storage in Lake Berryessa).

But in general, ecosystem managers reacted to drought-related emergencies rather than anticipating and preparing for them. CDFW and its partner agencies made extensive efforts to reduce the drought's impacts on native species. And the level of cooperation between state and federal agencies was, by the end of the drought, unprecedented. Yet this was all in response to drought, rather than in preparation for it, which limited its effectiveness. As an example, on some unregulated rivers, such as Deer, Mill, Antelope Creeks and the Russian River tributaries, CDFW sought to negotiate agreements with water users to leave water in the channels. The effectiveness of these agreements is largely unknown, due to limited monitoring information and water accounting.[22] Drought contingency planning and advance negotiations could have enabled CDFW to take action earlier at a larger scale.

Ineffective planning and priority setting also had a role in the struggles to manage cold water releases from Shasta Reservoir and limit salinity in the Delta. At Shasta, USBR failed to adequately consider the consequences of winter inflows to Shasta Reservoir that were both low and warm, making it difficult to manage cold water for salmon. And in the Delta, DWR and USBR had not conducted sufficient scenario testing of a warm, multi-year drought and its impacts on CVP and SWP operations. Instead, they had to rely upon a complex and highly contentious TUCP process to adjust operations and relax environmental standards.

## Recommended Reforms

Limited pre-drought planning and preparation leads to ad hoc decision making, increases risks to native plant and animal communities, and stokes controversy over drought responses. Based on the lessons from our case studies and other regions, such as Victoria, Australia, we recommend that California take steps to better prepare for drought and its impacts on ecosystems. Two complementary actions are needed: preparing and implementing watershed ecosystem plans that set priorities and identify tradeoffs, and creating annual watering plans that guide management in different types of water years.

### 1. Prepare and Implement Watershed Ecosystem Plans that Address Drought

California has numerous overlapping and uncoordinated plans for improving native species populations in freshwater ecosystems, prepared by an array of state and federal regulatory agencies, local governments, and stakeholders.[23] These plans reflect considerable investment in understanding vulnerabilities and opportunities for improving ecosystem outcomes. Yet poor integration of these efforts—and limited guidance on how to effectively manage water and other habitat resources under different hydrologic conditions—constrains their effectiveness.

To improve planning and preparation, we recommend developing watershed ecosystem plans for priority rivers. Watershed plans updated every 10 years would merge disparate planning and regulatory efforts, evaluate the status of ecosystems, set general priorities for action, and establish metrics for evaluating success.[24] These plans

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[22] Although small, voluntary flow releases by water-right holders helped fish trapped by low flows in some Russian River tributaries, these agreements were so few that they likely made no significant difference to watershed-wide outcomes.

[23] Some of these include recovery plans for species listed under the state Endangered Species Act, biological opinions and recovery plans for species listed under the federal Endangered Species Act, local habitat conservation plans (HCPs) and natural community conservation plans (NCCPs), regional and local conservancy efforts, the State Wildlife Action Plan, and the array of flow and water quality standards promulgated by the State Water Board and the Regional Water Quality Control Boards to support habitat and native species.

[24] The 10-year review interval is used in Victoria, Australia and appears successful. This creates a balance between the need to update plans regularly due to changing conditions and understanding versus the need to provide certainty and assurances to other water users.

would integrate all ecosystem management efforts within a watershed—including allocation of water and habitat restoration—into a single document that sets priorities for investments and focuses on building capacity to weather droughts. A useful model is the Regional Sustainable Water Strategies used in Victoria, Australia to coordinate on-the-ground ecosystem management actions.[25]

Because plans should be tailored to meet challenges specific to their watersheds, each is likely to be different. A few issues to consider include:

- **Decide on the right scale.** The size and number of watersheds covered by a single plan would vary, depending on the region and the resources to be managed. Many watersheds are nested within larger river basins, requiring integration of actions, perhaps through a master plan.[26]
- **Use ecosystem-based approaches.** Plans should move away from focusing on one or more species listed under state and federal Endangered Species Act laws, and instead consider actions that improve the physical and biological attributes of ecosystems to achieve a range of benefits or services (Hanak et al. 2011, Moyle et al. 2012). These ecosystem attributes—such as hydrologic connectivity, physical and biological complexity, hydrologic variability (including periodic disturbances), plant and animal community structure, and water quality—are better measures of ecosystem condition and are different from traditional single-species population measures.[27]
- **Integrate a range of stressors.** Drought management focuses, logically, on the allocation of water during times of scarcity. But physical habitat and other stressors that can be addressed prior to drought can play an equally important role in mitigating drought impacts and promoting recovery. Most large conservation plans identify improved quantity and quality of physical habitat as an objective, but this is often treated separately from plans for water allocation and management.
- **Acknowledge tradeoffs and set priorities.** Perhaps the most important task is to establish priorities for actions both before and during drought. This involves systematic evaluation and comparison of actions, with the goal of determining which are most important and which are most likely to succeed (Box 3). Setting priorities helps to avoid the common mistake of making all objectives equal or pursuing actions that have a low probability of success at a high economic cost.
- **Build social license.** It is critical that stakeholders understand the rationale behind investments to meet ecosystem goals and have substantive input into solutions—part of the what water managers in Australia call "building social license" for actions. This is especially important if solutions involve reallocation of water or changes in land use. Stakeholder involvement also improves understanding of watershed conditions and is an important source of ideas. Stakeholder groups can play a critical role as partners in improving physical habitat in watersheds that have large amounts of privately owned land.[28]

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[25] Regional Waterway Management Strategies for Victoria, Australia, are found in the Department of Land, Water and Environment Planning webpage.

[26] A master plan would be appropriate where individual tributary plans do not account for the ecological needs of the river system below the confluence of each tributary. For example, the volume and timing of flows needed to enable salmonids to migrate through the Delta and lower reaches of the Sacramento and San Joaquin Rivers may differ from the aggregation and timing of flows required on each of the upstream tributaries to provide suitable spawning conditions.

[27] For an excellent example of this ecosystem-based approach, see the 2016 report, *A Delta Renewed: A guide to Science-Based Ecological Restoration*, developed by researchers at the San Francisco Estuary Institute-Aquatic Science Center for the California Department of Fish and Wildlife. The authors propose a process-based approach to restoring ecosystems in the Delta that seeks to improve conditions for multiple species simultaneously (San Francisco Estuary Institute 2016).

[28] As an example, during the drought many farmers volunteered to change irrigation practices—including timing and magnitude of diversion—to help maintain in-stream flows and to improve wetlands for migratory waterbirds. More generally, organized stakeholder groups, in cooperation with environmental organizations, have had great success in improving physical habitat. Examples include the Central Valley Joint Venture, which seeks to improve bird habitat throughout the Central Valley, and the newly formed Central Valley Salmon Habitat Partnership, which seeks to improve populations of winter- and spring-run Chinook salmon and Central Valley steelhead. Both partnerships involve federal, state, and local agencies— including irrigation districts—along with environmental organizations.

### Box 3: Priority Setting for Watershed Plans: Seven Criteria

Setting priorities is potentially the most difficult task in ecosystem management planning, since it involves explicitly identifying tradeoffs and advancing some objectives over others. Systematic evaluation and comparison of actions can be used to make these difficult assessments. Possible criteria include:

1. **Extent and significance of expected benefits.** This could include investments in physical habitat or changes in flow regime, with clear explanation of expected ecosystem benefits, particularly to plant and animal communities, and how these build the capacity to weather droughts.
2. **Likelihood of achieving benefits.** This weighs the scientific uncertainties inherent in any action and assesses the likelihood of achieving the prescribed benefits. It also prescribes ways to reduce uncertainty through monitoring and research programs.
3. **Feasibility of action.** This examines financial, infrastructure, institutional, or legal constraints on actions.
4. **Efficiency of action or cost-effectiveness**. This evaluates whether actions require unacceptably large investments in resources (land, water, or funding) relative to other available options.
5. **Potential of an action to generate multiple benefits**. Such benefits might include groundwater recharge, recreation, improved supply to downstream users, or carbon sequestration.
6. **Implications of not undertaking an action.** This identifies the potential for near-term or permanent losses of key ecosystem attributes.
7. **Ability to support benefits over the long term.** This examines the capacity for continuing funding for operations and maintenance of habitat, continued supply of water, and monitoring and reporting.

## 2. Develop Annual Watering Plans

Rather than choosing from options considered in advance, managers often delay decisions about ecosystem water use until they know how much water is likely to be available to them. Such information typically first becomes available in midwinter, when reasonable estimates can be made about available runoff and water in storage. Under these circumstances, decision timelines become compressed, reducing opportunities for scientific analysis and stakeholder engagement. During the 2012–2016 drought, this uncertainty was very important in the complex efforts to manage the Delta and cold water reserves in upstream reservoirs such as Shasta, as well as other reservoirs.

Water managers in Victoria, Australia also faced this problem. They began developing "seasonally adaptive annual environmental watering plans," guided by their watershed plans. These plans identified and scoped critical water use decisions in advance of the wet season, then adjusted course during the wet season and immediately afterwards, depending on precipitation. We recommend that California adopt this approach.

For example, managers would prepare an annual watering plan each fall before the winter wet season. This plan—derived from the watershed plan's objectives—would focus on actions that managers will take in the coming year. Some actions would be investments to improve physical habitat or reduce other stressors as described in the watershed plans. Plans for use and allocation of ecosystem water would be contingent upon water conditions in the past and the amount and timing of precipitation in the year ahead. Table 6 presents a conceptual example of an annual watering plan for a regulated river system, with different scenarios parties would consider for the coming water year, depending upon prior conditions. For instance, actions planned for another dry year coming on the heels of three dry years, would likely be somewhat different than dry year actions following a very wet year.

One of the Victorian annual watering plans' strengths is their engagement process. The plans establish priorities depending on water year type, including identifying clear tradeoffs and potential effects on other water users. These priorities are then scenario-tested with stakeholders and water managers to evaluate impacts on other sectors. This approach improves water management through local knowledge and reduces controversy over decisions made during the water year.

**TABLE 6**

Sample objectives and priorities for annual watering plans, in anticipation of different types of water years

| Objectives | Critically Dry | Dry | Above/Below Normal | Wet |
|---|---|---|---|---|
| Long term ecosystem objectives | Improve ecosystem functions as defined in the Watershed Ecosystem Management Plans | | | |
| Short term ecosystem objectives | Avoid irreversible change in priority waterways and retain capacity to recover | Maintain basic ecosystem conditions in priority waterways to minimize native species population declines | Sustain desirable ecosystem conditions and healthy populations of native species in priority waterways | Improve ecosystem conditions and rebuild native species populations |
| Annual management objectives | ▪ Avoid catastrophic loss of key habitat<br>▪ Protect priority refugia<br>▪ Limit losses of high risk species | ▪ Maintain highest priority ecosystem functions<br>▪ Maintain connectivity to important refugia | ▪ Improve ecosystem function and physical habitat quality | ▪ Maximize plant and animal recruitment opportunities<br>▪ Expand area of high quality habitat |
| Ecosystem water priorities | ▪ Deliver water to priority refugia<br>▪ Release cold water for temperature-sensitive fishes<br>▪ Store some water for additional dry year | ▪ Provide water for priority ecosystem functions<br>▪ Take advantage of uncaptured flow events<br>▪ Store some water for additional dry year | ▪ Provide water to meet multiple flow objectives<br>▪ Support wetland expansion and floodplain flows<br>▪ Manage water to provide large watering events<br>▪ Store water above and below ground for various purposes | ▪ Provide water for all flow objectives<br>▪ Provide large watering events and store water for future large watering events and dry years |
| Watershed activities | ▪ Protect refugia and critical habitat<br>▪ Implement invasive species control measures<br>▪ Increase monitoring of critical waterways and reservoirs<br>▪ Relocate species if feasible<br>▪ Purchase water on spot market<br>▪ Negotiate agreements to leave water in streams or flooded fields<br>▪ Monitor illegal diversions and discharges | ▪ Protect refugia and critical habitat<br>▪ Undertake invasive species control measures<br>▪ Increase monitoring of critical waterways and reservoirs<br>▪ Increase water trading<br>▪ Monitor illegal diversions and discharges<br>▪ Prepare floodplain and wetland habitat for wetter years | ▪ Expand connectivity and quality of channel, riparian, wetland, and floodplain habitats<br>▪ Increase water trading and surface and groundwater storage agreements<br>▪ Reintroduce species into suitable habitat<br>▪ Negotiate agreements to maximize beneficial floodplain inundation | ▪ Implement post-flood restoration actions<br>▪ Expand connectivity of physical habitat<br>▪ Take advantage of disturbance in riparian and floodplain habitats to promote native vegetation |

SOURCE: Based on authors' observations.

NOTE: Refugia are geographic areas where populations of organisms can survive periods of unfavorable conditions, such as severe drought.

## A Process for Developing and Implementing the Plans

Given the diverse array of watersheds, issues, and interests, there is unlikely to be a single formula developing and administering these plans. The plans should fit the scale and problems of the watershed and the capacity of interests to engage in developing those plans. Here we provide some thoughts about how state agencies, along with key federal partners, can help foster and support this process and encourage broad involvement by local and regional watershed interests in crafting consensus solutions (Table 5).

### Identifying priorities

The state can advance the development of watershed planning and drought preparation by identifying priority watersheds. For example, CDFW has developed the State Wildlife Action Plan (SWAP).[29] The SWAP identifies terrestrial, aquatic, and marine conservation needs, sets goals and objectives for improving biodiversity, and develops regional plans—including generalized performance measures—for achieving the goals and objectives. In its current form, the SWAP is too generalized and coarse in scale to be used to specify watershed-level actions to prepare for and respond to droughts. (Indeed, the SWAP considers drought principally within the context of climate change, rather than as a current stressor.) But SWAP can be used to establish priority watersheds and guide the setting of objectives.

### Providing a regulatory impetus for action

The state can also stimulate the process of crafting consensus solutions. Good drought planning and preparation rarely happens spontaneously. Most successful efforts are a product of regulatory pressure—the threat of changes in regulatory conditions that may harm some interests—coupled with the willingness of agencies, water users, and stakeholders to collaborate in crafting solutions that meet broad objectives, often involving compromise.

Among our case studies, the Yuba River Accord (YRA) is perhaps the best example of the importance of a threat and the capacity to work collaboratively on a solution.[30] The YRA was the product of a threat—the State Water Board's proposal to amend water rights to allow for higher ecosystem flows—coupled with the willingness of a diverse array of federal, state, and local agencies, along with water users and environmental organizations, to negotiate a solution. After three years of negotiation and plan development, the State Water Board accepted the agreement in 2008 and amended local water rights accordingly.

The YRA anticipated and prepared for drought in ways that reduced impacts on both ecosystems and water users, while minimizing conflict. Through a conjunctive use program, farmers were switched to groundwater to leave more water in the river during dry years. Good monitoring and modeling programs helped maintain water temperatures to prevent die-offs of temperature-sensitive fishes. And significant investments in physical habitat organized and funded, in part, by the Yuba County Water Agency, helped ameliorate some of the drought's effects on salmon and steelhead.

Another example from outside California might also serve as a model for some watershed plans. The Yakima River has been the site of controversy over water supply operations and declining salmon stocks for many decades. In 2009, the State of Washington's Department of Ecology brought together representatives from the Yakima Nation; irrigation districts; environmental organizations; and federal, state, and local agencies to craft consensus solutions to the basin's issues. This was done in part under regulatory threats to reallocate water to meet ecosystem needs. After 18 months of negotiation, the Yakima Basin Integrated Water Resource Management Plan was issued, with a joint state and federal Programmatic Environmental Impact Statement.[31] Implementation of the plan is a work in progress, with many actions yet to be completed, but it retains significant (although not universal) support among agencies, water users, and stakeholders.

These two examples highlight the importance of a stimulus for action—usually involving the potential for regulatory changes—coupled with a willingness of interests in the watershed to negotiate a solution. Development

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[29] To receive funds from the federal Tribal and State Wildlife Grants program, states must update their SWAP every 10 years and have it approved by the US Fish and Wildlife Service. Although this program does not generate much revenue to California (less than $4 million annually in the past decade), the SWAP plan provides a useful framework for the kind of integrated, comprehensive, regional ecosystem-based planning we are recommending here.
[30] A description of the Yuba Accord can be found on the Yuba County Water Agency's website.
[31] The Yakima Basin Integrated Water Resource Management Plan website includes environmental documents and a history of this plan's development.

of the plans' key components can be completed relatively quickly, if the parties are willing. In the case of the Yakima Basin, the negotiators reached an agreement in 18 months.

There are many opportunities for stimulating consensus solutions in California. For example, the State Water Board is updating its water quality control plans for the Delta and its tributaries. The board has proposed solutions that many water users view as a threat. But it has also made clear it is open to negotiated solutions, recognizing that although imperfect, these solutions are likely to be more durable and effective than those imposed on water users.[32]

### Key stakeholder roles in plan development and implementation

Efforts to develop watershed plans should, in our view, be self-organizing where possible. In some cases, it is more effective for the effort to be led by local agencies, such as water districts that also have the capacity to implement the plans (good examples include the YRA, where the Yuba County Water Agency is a lead player, and Safe Harbor Agreements and Habitat Conservation Plans negotiated by the Sonoma County Water Agency on behalf of land owners). In others, state or federal agencies might be more effective at leading the plans.

Ultimately, crafted solutions and proposals for their administration and funding must meet the requirements of federal and state regulatory agencies that administer the relevant environmental laws.[33] Where efforts cannot meet these requirements—or in watersheds that lack the capacity to develop agreements—traditional regulatory approaches involving setting and enforcement of standards would be required.

## Establish Ecosystem Water Budgets

Although better accounting, planning, and preparation would improve the management of California's freshwater ecosystems, these reforms would be enhanced by a better system of water allocation to protect ecological uses. Where these allocation volumes were better defined during California's 2012–16 drought, ecosystem water management was simpler and likely more effective, particularly where the ecological priorities and implementation strategies were defined by negotiated agreements (e.g., the Yuba River and Putah Creek) or by legislation as is the case for the Central Valley Wildlife Refuges. Our interviews with water managers revealed, however, that the lack of flexibility in managing ecosystem water even in well run systems proved challenging. Ecological water management was more difficult and controversial where it relied principally upon minimum flow requirements to meet endangered species or water quality control plan directives. The lack of flexibility associated with these standards made it difficult to respond quickly and effectively as the drought unfolded. Where there were no management agreements or flow standards in place—which is the case for most streams in the state—there was usually no action taken to manage ecosystem water. Exceptions included the Deer, Mill, and Antelope Creeks and tributaries to the Russian River. These received attention because CDFW brought them to the State Water board for priority action to protect coho and Chinook salmon.

Based on the 2012–16 drought experience, we recommend that state and local water managers, water users, environmental and fishing advocates, and other interested parties consider the adoption of ecosystem water budgets (EWBs) for California's most important watersheds.

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[32] At the time of this writing it was unclear whether these negotiations will bear fruit. The Bay-Delta water quality control plans can be found at: http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/.

[33] For example, the watershed ecosystem and annual watering plans would have to be consistent with applicable water quality plans, water rights requirements, federal laws governing USBR facilities, and licenses issued by the Federal Energy Regulatory Commission. We discuss these consistency issues, as well as the role of the various state and federal agencies, later in this report.

The EWB would identify the volume and timing of water needed within each watershed to fulfill the purposes of the watershed ecosystem plans. EWB managing entities—or trustees—would use the water to support ecosystems, as guided by the annual watering plans. The trustees also would have authority to store, purchase, or exchange water to augment that assigned to the EWB, and to lease water to other parties during periods when the full allocation is not needed to achieve the ecological objectives set forth in the plans.

The existing system of ecosystem protections relies heavily on constraining the exercise of water rights, rather than integrating environmental management into the water rights and management systems. This structure has produced a situation in which different parties believe that ecosystems or water users bear a disproportionate burden of water shortages and regulatory uncertainty. The perception of ecological protection as a zero-sum game is especially pronounced during periods of drought.

In watersheds that already have ecosystem flows designated by existing regulations, all or most of this water would convert to the EWB, which could be managed with the same freedoms and efficiencies as other water rights. In other watersheds, EWBs could be developed using models for establishing necessary flow regimes to support ecosystem health. Once established, the EWBs would become the principal means of meeting environmental regulatory standards, consistent with the watershed ecosystem plans and annual watering plans.

This change offers multiple advantages over the current regulatory regime:

- The EWBs would be based on an integrated assessment of ecological goals set forth in the watershed plans, rather than the requirements of individual species.
- The EWBs would promote enhancement of aquatic habitat and reduction of stressors across different types of water years—both when water is relatively abundant and when water is scarce.
- The EWBs would afford greater flexibility, because they would be administered as an integral component of the water rights system, rather than as constraints on the exercise of water rights. This would enable all parties to engage cooperatively in water trading and exchanges, as well as above- and below-ground storage, to meet diverse water management goals.
- The EWBs would increase certainty for all parties, because water assigned to the EWB would be fixed for a period of years and would vary depending upon water year type.

More generally, EWBs would promote complementary management of water for ecosystems and for urban and agricultural supplies, and they would reduce conflicts among various water management objectives.

Transition from the existing system of environmental protection to EWBs would be best accomplished by negotiation among the interested parties within each watershed as part of the development of watershed ecosystem plans. Negotiated EWBs—like watershed plans—are desirable, because they can be tailored to the hydrology, ecology, and water uses of the individual watersheds, benefit from local knowledge, and have buy-in from the affected parties. The State Water Board, the state and federal fisheries agencies, and other state and federal entities can encourage negotiations by providing a regulatory impetus, along with technical assistance and other support to facilitate the process. But we anticipate that the details of successful EWBs are likely to reflect a consensus among the interested parties, rather than a government mandate.

The concept of an EWB is not new. Most other western states and several nations have established environmental water rights or water budgets (Box 4), and integrated them into overall water management.

The EWBs proposed here differ from, and should not be confused with, the "Environmental Water Account" (EWA) created by the CALFED Bay-Delta Program. The EWA provided a pool of "environmental water" that the CVP and SWP used to offset supply losses when they reduced export pumping to meet Delta water quality and flow standards. In contrast, EWBs could be negotiated for any of California's watersheds, and the primary purpose of the ecosystem water would be to promote healthy fisheries and aquatic habitat (rather than for the principal purpose of compensating for environmental mitigation requirements).

The proposed EWBs also differ from the water currently managed for instream beneficial uses under section 1707 of the California Water Code. This law allows existing water-right holders, with State Water Board approval, to dedicate water to instream beneficial uses. To date, instream water rights established under section 1707 exist in small volumes on a few rivers (Hanak and Stryjewski 2012). They augment (usually in modest ways) the existing regulatory standards that protect water quality, instream flows, and fish and wildlife. In contrast, EWBs would incorporate the water that is set aside under the regulatory standards and enable the more flexible and efficient management and use of that water.

## Recommended Reforms

Creation of ecosystem water budgets will require parties within watersheds to grapple with a variety of interrelated issues. Successful efforts will need to achieve four objectives:

1. **Define the EWB as an integrated component of the water rights system within the watershed.** This means identifying the purposes and places of use of water assigned to the budget, determining the quantity and timing of that water, and defining the EWB's relative priority within the water rights system. A robust accounting system is also essential to achieve this.
2. **Create a management structure for the EWBs.** A key question will be whether the EWB should be administered under the auspices of an existing entity (e.g., a local water agency, the State Water Board, or CDFW) or managed by new independent ecosystem trustees with the same rights and prerogatives of other water-right holders. The board's role in supervising the creation and management of the EWBs is also an essential issue.
3. **Grant the EWB management flexibility.** Tools such as trading and storage would enable the EWB manager to use the ecosystem water most efficiently—both for the benefit of fish and wildlife and for other water users within the system.
4. **Improve certainty in the allocation and management of ecosystem water.** The parties will need to agree on the appropriate term of the EWB and on ways of accounting for hydrologic, scientific, and regulatory changes that could affect ecosystem water management during the term of the EWB.

In the following pages, we suggest criteria and options for resolving these issues. A later section describes where new legislation may be necessary to enable the creation of EWBs and to guide their administration.

### Box 4: Environmental Water Rights and Budgets in Other Jurisdictions

Beginning in the late 1970s, most western states have authorized state agencies—and, in some cases, private parties—to hold instream water rights for environmental purposes.

Today, Arizona, Colorado, Idaho, Montana, Nebraska, Nevada, Oregon, South Dakota, Utah, and Wyoming recognize new instream appropriations and allow existing water-right holders to dedicate or transfer water to environmental instream uses. Arizona, Montana, and Nevada also permit private parties to appropriate water for instream environmental purposes. Texas has created a water bank that includes the Texas Water Trust, which holds water rights dedicated to environmental needs. The Kansas and Oregon instream water right statutes both expressly authorize the storage of water for later release to support water quality, fish and wildlife, and other instream uses. And, as noted in the text, California recognizes the dedication or transfer of existing water and water rights to instream uses, but it does not allow new instream appropriations (Szeptycki et al. 2015).

The volume and significance of water held as instream water rights varies significantly across the West. For example, as of 2015 only one appropriative right in Wyoming had been converted to an instream flow right, and the handful of new instream appropriative rights had very recent priority dates, and were therefore junior to most other water rights (Szeptycki et al. 2015). In contrast, the Oregon Water Resources Department "has converted more than 500 of the state's minimum perennial stream flows to instream water rights, and has issued more than 900 state agency-applied instream water rights." Oregon also has more than 1,100 individual instream leases, instream transfers, and allocations of conserved water that provide water for fish and wildlife, recreation, and pollution abatement. Significantly, about 70 percent of this water carries senior rights (Oregon Water Resources Department 2009).

Other countries also have developed innovative methods of managing environmental water. Australia has environmental water entitlements (i.e., water rights) that are managed by independent environmental water holders (Mount et al. 2016a). This water is on an equal legal footing with the rights of urban and agricultural water uses, and shortages are apportioned equally. State governments develop plans for implementing environmental watering requirements and actively engage in water trading. Purchases of water from existing water users have been the principal source of this environmental water.

Following the end of apartheid, South Africa established catchment management agencies (CMAs) for its waterways and instructed the agencies to establish minimum environmental reserves of water with high priority rights. The reserves must ensure the quantity, quality, and reliability of water needed to maintain the ecological functions on which humans depend and ensure the long-term sustainability of ecosystems. Where rivers are out of balance, CMAs must establish plans to reduce diversions that allow water users to adjust to reduced supplies. Stakeholders are actively involved in setting the levels of the environmental reserves, but are guided by scientists. Tanzania has adopted a similar approach to establishing minimum environmental flows (Hirji and Davis 2009).

## 1. Define EWBs as an Integrated Component of the Water Rights System

The most important action required to create an EWB is to define how the water within the budget will integrate into the water rights system for each watershed. This also may be the most contentious aspect of the process, because it requires the parties to determine the purposes and places of use of water assigned to the EWB, specify its quantity and timing, and designate its priority (or priorities) relative to other water-right holders. All aspects of the EWB would be described within the watershed and annual watering plans.

### Purposes and Places of Use

The use of water within the EWB would be guided by the watershed ecosystem and annual watering plans. As described above, their key purposes are to anticipate hydrologic variability, to define and prioritize ecological objectives under differing hydrologic conditions, and to provide a roadmap for the deployment of available ecosystem water within the watershed (as in Table 6). These plans would seek to improve ecosystem functions in support of multiple species, not just one or a few listed species that are the focus of most existing regulatory water quality and flow requirements.

### Quantity and Timing

The quantity of water assigned to each EWB must be sufficient to provide the water quality, flows, temperatures, and other ecological attributes needed to support healthy populations of fish and other aquatic species. These quantities would vary by season, type of water year, and other relevant factors, including spawning, migration, and habitat-maintenance flows needed for priority species.

The EWB's targeted flows should be "functional flows," which provide specific ecosystem functions beneficial to native species (Box 5). California's rivers are dynamic, with rapid and often large changes in flows across days, seasons, and years. Freshwater species are adapted to this variability, with requirements tightly coupled to river flow dynamics. For example, early winter freshets trigger juvenile salmon migration; reproduction of foothill yellow-legged frogs is synced with the decline in snowmelt every spring. Some native fish breed on seasonally inundated floodplains, where juveniles take advantage of productive, slow-moving waters. As river flows decline or cease in the summer dry season, native fish, amphibians, and insects disperse in search of refuges or burrow into the ground, becoming dormant until flows return.

The EWB must incorporate this dynamic ecology by providing water to augment existing system and uncaptured flows when necessary to create seasonal and inter-annual variability. These biological objectives, as well as the specific times and stretches of river where theses functional flows are most needed, would be outlined in the ecosystem and annual watering plans for each watershed.[34]

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[34] As with water allocated to water quality and instream flow purposes under the existing regulatory laws, ecosystem water that fully serves its defined purposes at the places of use designated in the watershed ecosystem and annual watering plans would return to the system. On many rivers, this water would remain available for diversion by downstream water-right holders as it is today. On rivers such as the Trinity (including the lower Klamath)—where the instream purposes and places of use extend to the confluence with the ocean—downstream diversions for consumptive uses are not possible.

## Box 5: Functional Flows

In principle, restoring natural flow patterns should improve the environmental conditions to which species are adapted, and improve their persistence. In practice, however, this is seldom possible. Dams, levees, and other water infrastructure alter the timing and distribution of water and constrain how environmental flows can be allocated. Physical degradation of river channel and floodplain habitats can also make natural flow regimes suboptimal for achieving desired ecosystem outcomes.

A functional flows approach targets key components of the flow regime that control important physical, biochemical, and ecosystem functions (Yarnell et al. 2015). Five commonly identified components are: wet-season initiation flows, peak flows, spring recession flows, summer base flows, and inter-annual variability. These components vary in importance locally. For example, inter-annual variability may be less relevant in stable, groundwater-fed streams, while spring recession flow is particularly important to snowmelt-fed rivers. Different ecosystems and their species have different functional flow needs.

Functional flows are quantified by assessing flow patterns in rivers and streams that have relatively pristine conditions. These "reference" streams can be found throughout the state and have been classified according to similarities in their flow regimes (e.g., with flows driven by snowmelt, runoff from rainfall, or seepage from adjacent groundwater basins). Within each class, the natural variability of functional flow components is characterized by their magnitude, timing, duration, frequency, and rate of change under different water year types. Once defined, these characteristics can be used to estimate volume and timing of water for an EWB.

An advantage of the functional flows approach is that it focuses on ecosystem processes and outcomes, rather than the needs of single species. It preserves the natural variability of flows to which native species are adapted, but prioritizes those aspects of the flow regime that sustain critical ecosystem functions. In some cases, a functional flows approach may require less water than other approaches that seek to restore natural variability, such as reserving a fixed percentage of unimpaired flows. Physical habitat restoration, including the reconnection of floodplains with the river channel, will often be required to realize the ecosystem benefits of functional flows.

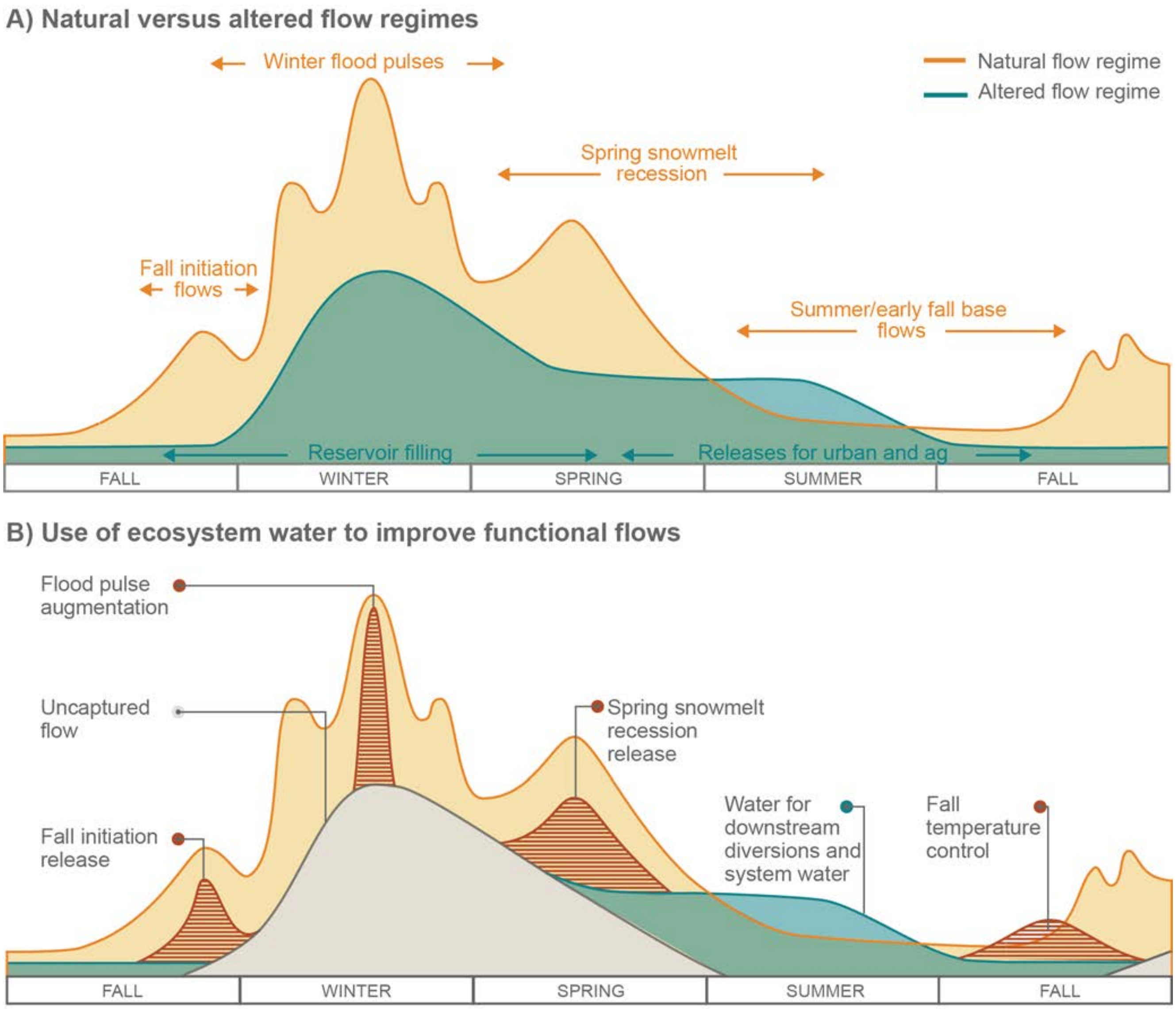
In regulated river systems, the timing and magnitude of deployment of EWB water would be designed to create ecological functions that native species have adapted to, and to provide flow augmentation to aid specific events such as spawning and migration. This flow regime also would recognize that water is generally abundant for all uses during the winter and spring months and becomes increasingly scarce in the summer and fall. The magnitude of these functional flow pulses will depend upon the amount of water in the river to support downstream diversions, system water, and uncaptured water, and the availability and response of physical habitat (Figure 5).

One way to set these flows is by defining the EWB as an incremental volume of water—above flows available for water diversions and system water—that can be flexibly managed to create flow regimes that improve ecosystem conditions. This is the model used in Putah Creek. An alternative is to set aside a percentage of the flow that would have naturally occurred if there were no upstream storage or diversions—often called a share of "unimpaired flow." This is the approach the State Water Board has proposed for new ecosystem flows on the tributaries of the San Joaquin River.

The advantage of the latter approach is that it reliably establishes seasonal variability in flows that native species are adapted to. The disadvantage is that a fixed percentage reduces the flexibility needed to sufficiently augment flows to achieve ecosystem functions. This is especially important in highly altered river systems where occasionally large pulses—higher than the allotted percentage—are needed to achieve ecological results (for example, winter flooding of riparian and floodplain areas). To be most effective, defining EWBs based on a percentage of unimpaired flow would have to be paired with flexible management of that allotment of water (Mount et al. 2016b).

**FIGURE 5**

Natural and altered flow regimes, and how EWBs could improve functional flows




SOURCES: Based on authors' experiences in California and a recent review by Yarnell et al. (2015).

NOTES: Panel A compares a natural flow regime and a flow regime altered by water storage and diversion. The most biologically important functions of the natural flow regime are labeled. The second panel depicts how strategic releases of an EWB (hatched red areas) on top of uncaptured flows (gray area) and water for downstream diversions and system water (blue areas) would create desired functional flows. The difference between the natural flow regime (yellow) and the flow regime created by the combination of uncaptured flow, release of EWB and water for downstream diversions and system water is water stored during the wet season.

The volumes of water assigned to the EWB would not necessarily be the same as those dedicated to ecological purposes under the current regulatory system. The EWB could be greater in watersheds where the existing regulations have proved inadequate to meet the goals of healthy and sustainable fisheries and ecosystems. But it also could require less water—or change the timing and uses of that water—because the EWB would be based on an integrated determination of the needs of the whole ecosystem, rather than fragmented regulatory assessments of individual species requirements.

Management of EWBs can be compatible with water supply for downstream users that benefit directly from EWB water. As an example, most of Putah Creek's natural flow is stored and diverted for irrigation, but modest amounts of ecosystem water allocated through a functional flows approach has effectively restored native fish populations (Technical Appendix and Kiernan et al. 2012). Recognizing that ecosystems are dynamic and respond to many factors other than flow, the functional flows approach may be most effective if applied in an adaptive management framework, where responses to water allocations are carefully monitored and used to inform subsequent flow and non-flow related management activities.

Parties to the watershed negotiations would likely recognize that the efficiency of ecosystem water deployment can be improved through investments in physical habitat improvements and their connectivity to the river (for example, floodplain restoration or channel margin habitat that benefits juvenile salmonids). This creates an incentive to explore and implement strategic habitat investments that could reduce the amount of EWB water needed to meet the objectives of the watershed ecosystem and annual watering plans.

As with the existing water quality and flow standards that govern California's most significant river systems, the quantity of water assigned to the EWBs would be greater during wet years, and less during dry years when supplies are scarce for all uses. This emphasizes the need to develop priorities for EWB use in different types of water years, as illustrated previously in Table 6 and the discussion of annual watering plans.

### Priority

The third important detail needed to integrate the EWB into the water-rights system is to define the priority of ecosystem water relative to other water rights. Although the negotiating parties would have an array of options, they should be guided by the sources and purposes of the water that comprises each EWB.

The principal source of this ecosystem water is likely to be the water currently used to comply with the laws and regulations that protect water quality, fish and wildlife, and other instream beneficial uses as described in Box 1.[35] This is appropriate, because the EWB's purpose is to implement these regulatory protections, but to do so in a manner that focuses on multiple species, integrates into watershed management efforts, and is more efficient and flexible to administer.

The parties to the EWB negotiations therefore should designate at least a portion of the assigned ecosystem water as the first priority within the watershed. The precise quantity of water that would carry this top priority should be determined through the functional flows analysis described above. This block of first priority ecosystem water will vary based on season and water year classification, however, and thus would adjust to system-wide water abundance and scarcity as do the existing regulatory standards.

In this respect, the EWB would operate within the water rights system in a manner similar to the water now assigned to meet regulatory requirements. For example:[36]

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[35] As described below, the trustees also could augment the EWBs through purchases and donations of water from existing water-right holders under Water Code §1707. This acquired water would carry the same priority relative to other water rights as the priority held by the transferor.

[36] See the details of these case studies in the Technical Appendix.

- USBR stores water in Shasta Reservoir for later release to maintain flows and temperatures in the Sacramento River for the benefit of migrating salmon and to protect water quality in the Delta. These obligations, which are set forth in its water-right permits and in the BiOps governing CVP operations, take precedence over USBR's water supply commitments.
- Under the terms of the Yuba River Accord, the Yuba County Water Agency stores and releases water to support salmon and steelhead. These storage and release requirements vary by season and water year classification (Yuba County Water Agency 2010). The agency also must fulfill these obligations as a condition of its water-right permits (State Water Resources Control Board 2003 and 2008).[37]
- In the Russian River system, surface water- and groundwater-right holders must cease diversions under conditions that would lower river flows and jeopardize spawning salmon. This directive—based on the State Water Board's power to ensure the reasonable use of water and to protect the public trust—applies to all types of water rights, including riparian rights and pre-1914 appropriative rights (California Court of Appeal 2014).

These actions—and many like them in other systems—were adopted as part of the legal authorities described in Box 1. All recognize an effective top priority for ecosystem water within their respective watersheds to the extent that such water is needed to comply with those laws.[38]

There are at least two ways to integrate the priority of the EWB into the water rights system. The first, and simplest, would be for the parties to agree that ecosystem water carries first priority. This approach would rely on the EWB's variable quantities to provide the appropriate division of water between the EWB and other water-right holders during periods of relative water abundance (both seasonal and inter-annual) and relative scarcity. This is how water dedicated to environmental uses is defined and managed on a number of important rivers, including the Trinity, Yuba, Tuolumne, and main stem of the San Joaquin.[39]

For example, the Trinity River Restoration Program (TRRP), which is administered by USBR and the US Fish and Wildlife Service, creates "a variable flow regime based on five water year types to mimic natural flows" (Trinity River Restoration Program 2016a). The seasonal flow schedule includes base flows during most of the year with pulse flows to aid salmon migration from mid-May through mid-July. It also includes variable temperature targets. Figure 6 shows the variable inter-annual allocation of water to ecosystem uses. Within the limits of these assigned quantities, USBR's obligation to release this water to fulfill the TRRP's water quality and flow objectives takes precedence over its water supply commitments to CVP contractors (US Court of Appeals 2017).

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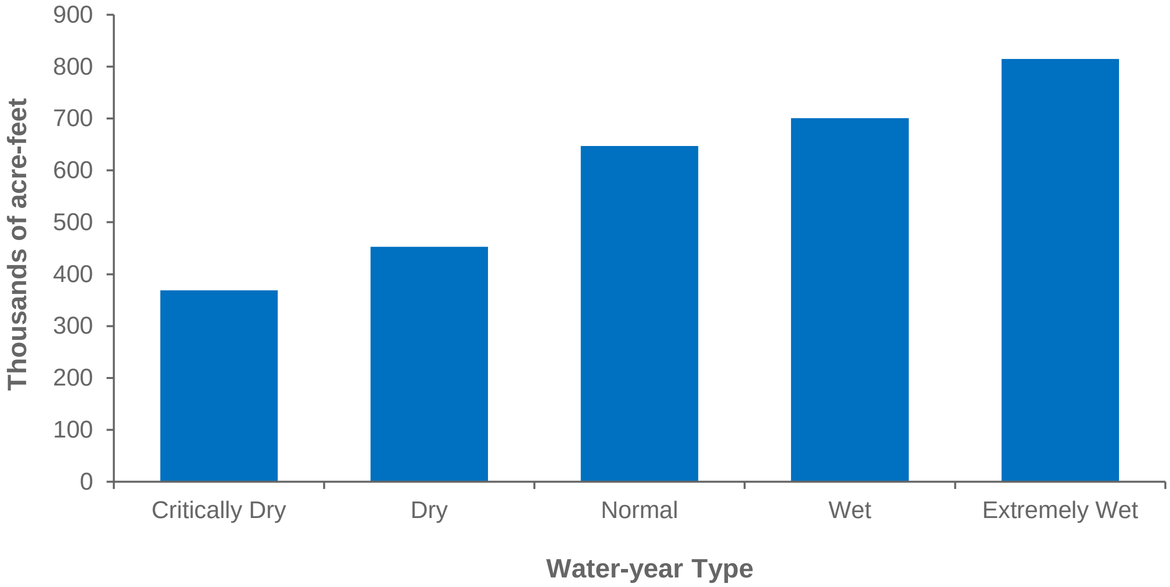
[37] These requirements are also likely to be incorporated into the revisions to the agency's license with the Federal Energy Regulatory Commission (Yuba County Water Agency 2012).

[38] Under extremely dry conditions, where there is not enough water to supply essential domestic uses within the watershed, the ecosystem water allocation likely would have to be reduced to ensure basic human rights to water (Gray et al. 2015). It is unlikely that such conditions would arise for domestic water use within regions that import water from other watersheds, however, as these large municipal systems (located primarily in the Bay Area and Southern California) generally have diverse sources of supply and the ability to manage demand during drought, as well as the capacity to share water to address localized shortages within their regions (Mitchell et al. 2017).

[39] The details for the Trinity River are set forth in the text. The variable flow regime for the Yuba River is described in Yuba County Water Agency (2010). San Francisco's detailed and nuanced schedule for releasing water from O'Shaughnessy Dan to support fish and wildlife, wetlands and whitewater recreation in the upper Tuolumne River is described in San Francisco Public Utilities Commission (2014). San Joaquin River Restoration Program (2017) describes the restoration flow schedule for that restoration program.

**FIGURE 6**

Restoration flows on the Trinity River vary significantly by water year type




SOURCE: Trinity River Restoration Plan (2016b).

NOTES: The figure shows restoration release water allocations by water year type. These releases are based on forecasted annual river runoff classifications that range from more than 2 million acre-feet per year (extremely wet) to less than 650,000 acre-feet per year (critically dry).

A second approach would be to assign a fixed quantity of ecosystem water to the EWBs, but define variable priorities that would determine the availability and use of that water in different water year types. Under this approach, the quantity needed to serve the most essential ecological functions—such as directing flows to key refugia to guard against the risk of catastrophic losses or extinction—would be designated first priority, followed by water needed to ensure adequate flows, temperatures, and other essential water quality criteria determined by ecosystem management and annual watering plans. Depending on the severity of periodic droughts, these lower priority uses would share in shortages within the system. This sharing could be in strict accordance with the water rights priority system, or the parties could agree to commensurate reductions between EWB uses and other classes of water-right holders. The CVPIA wildlife refuge water supplies—which may be reduced during drought by the same percentage as the CVP water rights settlement and exchange contractors—could provide a useful example of the latter approach.[40] Table 7 presents a simplified illustration of a water rights priority schedule for four types of water years that includes this type of division of ecological water within the EWB.

[40] See Table 4 and the case study in the Technical Appendix.

**TABLE 7**
Illustrative priority schedule and water allocations for EWBs and water rights in different water years

| Seniority | Critically dry | Dry | Above/below normal | Wet |
|---|---|---|---|---|
| EWB priority 1 | 75% | 100% | 100% | 100% |
| Most senior water rights | 75% | 100% | 100% | 100% |
| EWB priority 2 | 50% | 75% | 100% | 100% |
| Intermediate water rights | 25-50% | 50-75% | 75-100% | 100% |
| EWB priority 3 | 0% | 25% | 50% | 100% |
| Most junior water rights | 0% | 25% | 50% | 100% |
| EWB priority 4 | 0% | 0% | 25% | 75-100% |

SOURCE: Author example of a conceptual priority schedule of EWB water rights.

NOTES: For simplicity, the water rights have been grouped into three categories: most senior (riparian and pre-1914), intermediate (senior permittees and licensees), and most junior (junior permittees and licensees). In reality the water rights on most river systems are considerably more nuanced. The EWB priorities signify: 1st priority = prevent significant risk of catastrophic species losses or extinction; 2nd priority = assist spawning and migration of native species; 3rd priority = recover native species and improve ecosystem resiliency; 4th priority = enhance aquatic habitat. These objectives and priorities are for illustrative purposes only. In practice, the specifics of each would be explained in detail in the EWBs based on the analyses and priorities set forth in the watershed ecosystem and annual watering plans.

Both of these approaches could be used to develop EWBs that provide water to support key ecosystem functions and species needs in different types of water years. Indeed, they could result in exactly the same water allocations. However, the first approach to priority might be simpler to implement and the easiest for all parties to understand.

## 2. Create a Management Structure for the EWBs

The parties to the EWB negotiations also must decide how best to manage the water assigned to ecosystem uses. This decision should be guided by three principles: First, the management structure should facilitate flexible deployment of ecosystem water to ensure the water quality, flows, temperature, and other habitat requirements for fish and other aquatic species. Second, consistent with amount and priority of the water within the EWB, the ecosystem water manager—or trustee—should have authority to call for release of ecosystem water stored in upstream reservoirs and to seek to curtail diversions by junior water-right holders during periods of shortage. Third, the trustee's actions should be guided by the ecosystem and annual watering plans, which will also be used to measure performance.

There are three basic models for the ecosystem trustee:

- Representative trustee. One option would be to create an ecosystem trustee to represent the various interests within the watershed. These interests could include environmental and fisheries advocates, water users, dam operators (on regulated rivers), local government and tribal officials, and representatives from the CDFW or the federal fish and wildlife agencies. The parties could designate one entity as the trustee, with the others serving as an advisory or oversight council. This would both increase the efficiency of day-to-day decision making and assign accountability to a single entity or individual. It also would allow the parties to take advantage of existing expertise, professional staff, and funding. The Yuba County Water Agency's role in managing ecosystem water under the Yuba River Accord is an example of this approach; USBR and the US Fish and Wildlife Service have a similar role on the Trinity River.[41]

[41] The Yuba County Water Agency serves as administrator of the Yuba River Accord. The agency manages the water reserved by the accord for instream flows and habitat improvements based on scientific analysis and recommendations from the Yuba River Management Team (Yuba County Water Agency 2013). The Trinity

- **State agency trustee.** Alternatively, a state agency could agree to serve as ecosystem trustee. A logical option would be to have the CDFW assume this role, as it is the agency with principal responsibility to protect the state's fish and wildlife resources. Investing it with new authority to manage the water assigned to California's EWBs would enhance its stewardship capacities. An alternative would be to assign the responsibilities to the State Water Board, perhaps in a new office of Public Trust Advocate. The advantage of the latter arrangement would be to locate the trustees within the agency that is both charged with overall administration of California's surface water systems and vested with the most comprehensive authority over water rights and water quality.
- **Independent trustee.** Although the first two alternatives afford a variety of benefits, they also have a significant drawback: They would vest authority to manage the ecosystem water in entities that have broader water management obligations or regulatory responsibilities. Therefore, the negotiating parties may want to consider designating an independent ecosystem trustee or board of trustees who would have authority to manage the water assigned to the EWB as other water-right holders manage their water rights.

  Independence from other water-right holders and water users has the advantage of avoiding potential competing or conflicting obligations on the part of the trustee.[42] Similarly, independence from regulatory agencies, such as the State Water Board or CDFW, has the advantage of avoiding potential conflicts when the trustee's management decisions could affect other water-right holders or environmental interests.[43] When conflicts arise over EWB management, the parties to the controversy should not be the same as the entities that must resolve those conflicts. Designation of the board or CDFW to serve as trustee therefore may not be the most desirable option.
- **Office of Ecosystem Trustees.** In addition, the state could facilitate EWB management by creating an Office of Ecosystem Trustees (OET) within the Natural Resources Agency. This office would supervise the work of the trustees within the watersheds that have adopted EWBs. Its responsibilities would include monitoring implementation of the various EWBs and evaluating the effectiveness of the deployment of ecosystem water to achieve the watershed ecosystem and annual watering plan objectives.[44]

  The OET and the individual trustees also would be able to draw on the expert personnel and resources of the CDFW and DWR (both of which are situated within the Natural Resources Agency) to help develop and revise the plans, to decide how best to use the ecosystem water, and to monitor both stream conditions and ecological responses to the EWB watering program. These resources would supplement those available to the ecosystem trustees from water managers, environmental interests, local governments, and other sources within the watershed.

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River Restoration Program (TRRP) has a similar management structure. The program is administered by USBR and USFWS in consultation with the Trinity Management Council (TMC), which "functions as a board of directors that sets the priorities and schedules for strategic implementation by the Program's Executive Director" (Trinity River Restoration Program 2017). The TMC also conducts or commissions studies on the hydrology and ecology of the Trinity River system that inform the TRRP's management of water released for fisheries purposes, as well as its program for long-term habitat improvements (See the Technical Appendix).

[42] As detailed in the Technical Appendix case studies, some water supply agencies have successfully served as stewards for the storage and management of water dedicated to fish and wildlife and other instream beneficial uses. The Yuba County Water Agency's implementation of the Yuba River Accord is an example, as is the Solano County Water Agency's administration of the Putah Creek settlement. Both agencies work cooperatively with a variety of other interested parties and water right holders. In contrast, the Trinity River case study is an example of the conflicts that may arise when an environmental steward (in that case, USBR) also has water supply responsibilities.

[43] The State Water Board has permitting jurisdiction over post-1914 appropriative rights. It also has significant authority under the public trust and reasonable use doctrines over all water-right holders, including riparians and pre-1914 appropriators. CDFW does not exercise direct authority over water rights, but it regulates the storage and diversion of water to protect species listed under the California Endangered Species Act.

[44] Coordination among tributary EWBs also may be necessary where the ecological requirements of the river system below the confluence of each tributary is not accounted for in the individual tributaries' EWBs. (The San Joaquin River below its confluence with its principal tributaries is one example.) The OET could serve as a forum for coordinating the administration of the tributary EWBs and, if necessary, adopting a master EWB for the entire river system.

## 3. Grant the EWBs Management Flexibility

Regardless of the choice of structure for managing EWBs, trustees must have flexible authority over ecosystem water to achieve the objectives of the watershed ecosystem and annual watering plans. To fulfill this mission effectively and efficiently, the trustees should have the same tools available to other water-right holders and water users, including the ability to store ecosystem water, to participate in conjunctive management programs, and to engage in water trading.

### Storing Ecosystem Water in Reservoirs

Storage is a vital aspect of effective water management, because it enables water managers and water users to smooth the natural irregularities of precipitation and runoff, to save water for later use, and to augment river flows and enhance water quality during droughts. On regulated rivers the EWBs should include storage rights consistent with the annual watering plans, and the trustees should be able to make calls on water from storage to implement the budget.

This arrangement is already a common feature of environmental water management on a number of California's most important rivers, including several examined in the case studies that accompany this report. USBR reserves a block of water in Trinity Reservoir that it releases to maintain favorable flows and water temperatures to support migrating salmon in the lower Trinity and Klamath Rivers. It also maintains a "cold water pool" in Shasta Reservoir that it uses to protect downstream temperatures in the Sacramento River when salmon are present. The Yuba River Accord and Putah Creek settlements both rely on releases of water stored in upstream reservoirs to provide flows for fisheries. San Francisco stores water in O'Shaughnessy Reservoir to provide flows in the Upper Tuolumne River to protect fish and wildlife habitat, to support whitewater recreation, and to provide water for wetlands. The San Joaquin River Restoration Program similarly sets aside a volume of water stored in Millerton Reservoir for seasonal release to support salmon and steelhead in the main stem of the San Joaquin.[45]

### Trading Ecosystem Water

To enhance flexibility, the trustees also should have authority to trade ecosystem water. They could acquire water—through purchase or donation—under Water Code §1707 to add to the EWB. Acquisitions could include short-term and long-term transfers and permanent acquisition of water rights. Consistent with §1707, this water would have the same priority relative to other water rights as it did before transfer. When appropriate, the trustees also could lease water to other users and use the proceeds to further the purposes of the plans, including future water purchases to augment water quality and flows during periods of drought, enhancement of riparian and aquatic habitat, and acquisition of land and water rights.[46]

### Ecosystem Water in Conjunctive Use Programs

Finally, the ecosystem trustees should be able to negotiate water exchanges that take advantage of both surface and underground storage availability. For example, a trustee might transfer surplus ecosystem water to an irrigation district in exchange for the district's agreement to release an equivalent volume of water later in the year as pulse flows to aid spawning salmon. Or, an irrigation district might agree to pump groundwater in lieu of diverting water from storage so that it can maintain an equivalent volume in its reservoir for later release when the

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[45] The first four environmental storage arrangements are described in the Technical Appendix. Releases of stored water from O'Shaughnessy Reservoir into the Upper Tuolumne River are described in San Francisco Public Utilities Commission (2014). For information on the San Joaquin River Restoration Program and the storage of water in Millerton Reservoir for restoration flow releases, see San Joaquin River Restoration Program (2017).

[46] Transfers of water to the EWB would require approval of the State Water Board under §1707. Transfers from the EWB should be subject to review by the board to ensure that the transfer would not unreasonably harm other legal water users.

trustee places a call on the water to augment water quality or streamflows to benefit migrating fish. The Yuba River Accord provides a good example of how this type of cooperative, conjunctive management of groundwater and surface water storage can benefit both ecosystem flows and other water users.

## 4. Increase Certainty in Ecosystem Water Allocation and Management

An important goal of the EWBs is to provide greater certainty about the allocation and use of ecosystem water for the benefit of all parties. Three strategies are likely to be essential to the achievement of this goal.

### Agency Approval of EWBs

Without major (and unlikely) changes in state and federal law, the EWBs would not displace the existing environmental standards that protect water quality, fish and wildlife, and other instream beneficial uses of water. Rather, the EWBs would incorporate all or a portion of the water currently used to comply with those regulatory standards, and would become the principal means of achieving them. Parties who seek to negotiate an EWB for a watershed therefore must define the relationship between the EWB and the continuing regulatory authority of the State Water Board and other agencies within the watershed.

One way to accomplish this would be to submit the negotiated EWB to the State Water Board for its review and approval. Indeed, we recommend below that the California Legislature enact enabling legislation that would outline the key requirements of the watershed ecosystem plans, annual watering plans, and EWBs, and require board approval of negotiated water budgets. Under this approach, the board could approve a negotiated EWB if it concluded that the budget would achieve the purposes of watershed ecosystem management and annual watering plans, would be consistent with (or improve on) the existing environmental regulatory standards, and would not unreasonably affect other legal water users.[47]

### Duration of EWB Terms

Duration of the EWB is also an important consideration. By fixing the quantity of ecosystem water, EWBs bring greater certainty to all users. The trustees must live within their defined budget or acquire additional water from willing sellers. This provides greater certainty for other water managers and water users about the amount of water available for their own uses. At the same time, environmental advocates would know that the water assigned to the ecosystem would be available as defined in the EWBs. This would protect against the types of encroachments on ecosystem water that can occur when water supplies are scarce, as we observed in some of our case studies.

The term of an EWB therefore must be long enough to afford the benefits of this relative certainty, but not so long that the EWB cannot adapt to changing hydrology, new infrastructure, revised scientific information, and feedback on their effectiveness in enhancing ecosystem functions.

Although the parties should be free to negotiate any term of their choosing, we recommend that the EWBs be fixed for 10 years, corresponding to the schedule for periodic review and revision of the watershed ecosystem plans. The parties may want to consider a shorter initial term to recognize that the EWBs are experiments. After that, a 10-year term would allow all affected parties to make investment and management decisions based on the knowledge that the division of water between ecosystem and other uses will be stable.

[47] As described below, for watersheds that include one or more state or federally listed species, the parties also would have to seek approval from CDFW, USFWS, or NMFS (and possibly all three). In those watersheds that include one or more hydroelectric dams licensed by the Federal Energy Regulatory Commission (FERC), EWB implementation also would require FERC approval—either during relicensing or by reopening an existing license.

### Regulatory Assurances

Finally, the negotiating parties should anticipate that, during the term of an EWB, a change in law or regulation may alter the allocation of water to environmental purposes. This could occur, for example, if the State Water Board were to amend water quality or flow standards or grant temporary urgency change orders that adjust these standards during droughts. New endangered species listings, changes in "take" limitations, or revision of biological opinions also could alter the allocation of water to environmental uses in ways that diverge from the terms of an EWB.

To anticipate these possible regulatory changes—and to address their potential to undermine the certainty of the EWB—the parties may want to seek regulatory assurances from state and federal agencies whose continuing jurisdiction poses risk. These assurances would not bar regulators from taking actions to implement and enforce the water quality laws and endangered species acts, but they could afford monetary compensation in defined circumstances.

For state actions, the best means of including assurances within the EWB would be through state enabling legislation, as described below. For federal actions, one promising approach may be cooperative agreements with the federal fish and wildlife agencies under section 6 of the federal Endangered Species Act (Arha and Thompson 2007, Gray et al. 2013). Alternatively, state assurances could be part of an approved Natural Communities Conservation Plan for each watershed managed through an EWB. Similarly, federal assurances could be included in section 7 consultations or habitat conservation plans for each watershed that contains projects or diversions subject to the directives of the federal Endangered Species Act (Mount et al. 2014).

# Is New Legislation Needed?

The three general reforms recommended in this report—improved accounting, better preparation for drought, and creation of negotiated EWBs—could all be adopted within the framework of existing law. There are details, however, for which state or federal enabling legislation or legislative guidance would be useful.

## State Law

To speed accounting reform, we recommend that the California Legislature consider a set of directives to the State Water Board, DWR, CDFW, and other state agencies to develop methods for more accurately determining water diversions, water use, and return flows. This legislation also could instruct the agencies to adopt new accounting criteria that better define system water, ecosystem water, and uncaptured water. To improve planning and preparation for droughts, legislation could establish processes and criteria for development of watershed ecosystem plans and annual watering plans, including establishing responsibilities for their preparation and approval. Finally, the legislature can facilitate the development of EWBs by setting criteria for determining water quantities, outlining essential powers and responsibilities of ecosystem trustees, and approval procedures by state agencies.[48]

In addition, legislation could address some of the detailed issues that will necessarily arise during the creation and administration of EWBs. Legislative guidance on the most important features of the EWBs—such as reservoir storage rights, spillage priorities, in lieu storage, water trading rules, and regulatory assurances—would be

[48] If the Office of Ecosystem Trustees (OET) proposal were to advance, legislation would be needed to create such a new entity with the Natural Resources Agency. This legislation should define the respective roles and responsibilities of the OET and the individual watershed trustees.

valuable. Legislation authorizing the ecosystem trustees to lease water that is temporarily surplus to the EWB's annual watering objectives would be especially useful, as it is not clear under existing law whether water assigned to environmental uses—but not held as an instream water right under §1707—is transferable. One option would be to define the EWBs as ecosystem water rights, whose water could be stored and transferred just as water held under existing appropriative rights may be stored and transferred. Another would simply be to authorize the ecosystem trustees to engage in these flexible management actions without formally identifying the EWBs as water rights.

## Federal Law

There appear to be no significant federal statutory impediments to the reform proposals in this report. Questions of federal consistency and compliance are likely to arise in two settings. The first are those watersheds that contain one or more dams operated under the federal reclamation laws. These include the Trinity, Sacramento, American, Stanislaus, and San Joaquin Rivers, as well as the Delta. In these systems, USBR stores and releases water for environmental purposes under many (and, in several systems, all) of the laws outlined in Box 1. Assignment of some or all water reserved for ecosystem uses under these laws to an EWB would not change USBR's obligation to meet its water quality and flow requirements. Once the State Water Board approves an EWB, it becomes an integral part of California's water rights system. And several federal statutes require USBR to comply with state water rights law, including the laws that protect water quality, fish and wildlife, and other instream uses.[49]

The second setting includes those watersheds that contain dams licensed by the Federal Energy Regulatory Commission (FERC). Prominent river systems with FERC-licensed facilities include the Klamath, Pit, McCloud, Feather, Yuba, American, Mokelumne, Stanislaus, Tuolumne, Merced, Upper San Joaquin, Kings, Kern, Eel, and Russian.[50] Section 401 of the Clean Water Act requires applicants for FERC licenses to obtain the State Water Board's certification that the project would operate in compliance with several laws, including state water quality and flow standards. Because the approved EWBs would be the principal means of implementing these standards within the watershed, the board would be able to ensure that FERC licensees comply with the requirements of the EWB through its §401 certifications.

A significant limitation on §401 certification, however, is that the conditions are fixed at the time of licensing and may not be changed during the term of the license, which may range from 30 to 50 years. In watersheds where there are one or more existing FERC-licensed dams, it may be impossible to include the licensee's dam operations in the EWB without reopening and revising the license to incorporate the EWB into the existing water quality and flow conditions set forth in the license. This caveat emphasizes the need for cooperative and inclusive negotiations within those watersheds where the EWB structure may be desirable.

In several watersheds FERC relicensing schedules may create opportunities for the negotiation of EWBs. For example, the Yuba County Water Agency's New Bullard's Bar Reservoir and related facilities are undergoing relicensing. The State Water Board will be conducting its §401 certification proceedings in late 2017 or early 2018. The state certification is likely to include the terms of the Yuba River Accord as embodied in the board's

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[49] Section 8 of the Reclamation Act of 1902 and §3406(b) of the Central Valley Project Improvement Act of 1992 direct USBR to comply with state water rights and water quality laws. In CVPIA §3406(a), Congress also added "mitigation, protection, and restoration of fish and wildlife" to the CVP's authorized purposes. Section 313 of the Clean Water Act requires federal facilities to comply with all federal and state requirements "respecting the control and abatement of water pollution." This directive applies both to the CVP and to other federal dams, including those operated by the US Army Corps of Engineers. Several other federal statutes, including the section 307(c) of the Coastal Zone Management Act and section 205 of the Energy and Water Development Appropriations Act of 2012 also emphasize the importance of consistency between federal and state water policies (Gray et al. 2013).
[50] There are 125 active FERC-licensed dams in California. For a complete list, see Federal Energy Regulatory Commission (2017).

2008 amendments to YCWA's water rights permits.[51] Following this model, upcoming and ongoing FERC relicensing proceedings could serve as forums for the negotiation of EWBs on several important river systems, including the Pit, McCloud, Feather, American, Tuolumne Rivers, and Merced Rivers.[52]

# Funding

Improved water accounting and development and implementation of the watershed ecosystem plans, annual watering plans, and EWBs, will require dedicated funding. A 2014 PPIC report estimated recent annual spending of about $700 million/year on freshwater ecosystems in California, with a funding gap of $400–$700 million dollars annually to cover the unfunded costs of a variety of species recovery, habitat conservation, and restoration plans. Approximately half of these costs is for work in the Delta and the greater Sacramento–San Joaquin watershed, and about half is for coastal and estuarine ecosystems. Many of the plans included in these estimates rely heavily on physical habitat restoration, without much attention to the mitigation of other environmental stressors, such as poor water quality, diminished flows, and invasive species, which could further increase costs, particularly under a changing climate (Hanak et al. 2014).

When not required as part of permitting or mitigation, these types of ecosystem related investments lack a natural local funding base. Some communities have approved fees or taxes to support their local watersheds, and a substantial share of the recent state general obligation bonds were earmarked for ecosystem improvements. Although the available funding has undoubtedly helped to support California's compromised aquatic ecosystems, the financial distribution process often fails to identify and prioritize those projects that are likely to deliver the greatest benefits. An improved prioritization effort—through the type of planning recommended here—could help develop clearer objectives and ways to measure the effectiveness of various actions. Funding could then focus more systematically on an integrated set of ecosystem goals and components with higher returns on investment of environmental dollars along with commensurate water accounting and ecosystem monitoring programs to guide and evaluate those investments.

As described above, the water for the proposed EWBs would be "funded" primarily by assigning all or a portion of the water reserved to meet environmental regulatory requirements to the ecosystem budgets. The ecosystem trustees also could raise funds through temporary sales of ecosystem water that is surplus to current needs, and use the proceeds of these sales to fund ecosystem improvements and to purchase water to augment the EWB during times of shortage. In addition, the trustees could acquire water or water rights under Water Code §1707—by purchase, exchange, or donation—to supplement the assigned ecosystem water. The trustees could also apply for funding from future water bonds that include ecosystem improvements and other public benefits.[53]

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[51] Detailed information about the relicensing can be found at YCWA's Public Website for the Relicensing of the Yuba River Development Project.

[52] There are 22 pending FERC relicensing petitions. For information on the FERC relicensing proceedings for Oroville Dam on the Feather River, see DWR's Oroville Facilities Relicensing webpage. Information on the relicensing of LaGrange Dam and New Don Pedro Dam on the Tuolumne River may be found on the Turlock and Modesto Irrigation Districts' joint Don Pedro Relicensing webpages. For information on the relicensing of New Exchequer Dam on the Merced River, see Public Website for Relicensing of Merced Irrigation District's Merced River Hydroelectric Project.

[53] Proposition 1, enacted by the California voters in 2014, authorizes $7.5 billion in bond funds for water supply infrastructure improvements, of which $2.7 billion will be allocated to fund the public benefits of those projects within the Sacramento–San Joaquin River and Delta system (California Water Commission 2017). The California Water Commission (CWC) will determine which projects qualify for these funds (Weiser 2017). Although the time to submit applications for this funding has passed, Proposition 1 does serve as an example of the type of bond revenues that could be made available in the future to acquire ecosystem water. Indeed, there may even be opportunities for ecological water acquisitions as components of the projects to which the CWC ultimately allocates Proposition 1 monies.

State bonds are a one-time funding mechanism, however, and cannot be counted on to provide a reliable stream of funding. A modest fee on water diversions or on water use within the watershed may be needed to generate more sustainable funding to support the EWBs and watershed plan implementation.

# Conclusion

Management of water to meet environmental needs is difficult during most years and is especially challenging during droughts, when water scarcity heightens tensions and limits management options. Yet it is during droughts that the greatest environmental harm occurs, contributing to long term decline in native species' populations and changes—often irreversible—in ecosystem conditions. The consequences of drought for freshwater ecosystems can last long after the rains return.

The California drought of 2012–16 included the driest and warmest four-year stretch in recorded history, with great harm to native plant and animal communities already stressed by the way Californians have managed water and land to accommodate a growing population and economy. Case studies of the response of institutions to the drought revealed three areas where reforms could not only improve ecosystem conditions, but also reduce conflicts over the allocation of water to the environment:

- **Improve environmental water accounting.** Conflict over the allocation of water to ecosystem uses is exacerbated by poor accounting systems. Better tracking of water availability and use will improve decision making. Debates over allocation should be informed by a proper classification of environmental water that separates water needed to support diversions by water-right holders (system water) from water set aside for ecosystem health (ecosystem water), along with water above and beyond those volumes that exceeds demands or cannot be captured with existing infrastructure (uncaptured water).
- **Plan and prepare for drought.** California was not well prepared for the ecological consequences of the latest drought. To prepare better for future droughts, the state needs new planning approaches and investments in actions that help reduce drought impacts. These should include watershed ecosystem plans that set clear goals and objectives for freshwater ecosystems, with an emphasis on setting priorities and improving ecosystem condition and function through actions before, during, and after drought. Annual watering plans are needed to define and publicly vet the planned and contingent uses of ecosystem water every year.
- **Establish ecosystem water budgets.** Management of water for the environment today relies on rigid, minimum standards for water quality and flows that are inconsistently applied during drought. Most California streams have no flow standards at all. California should encourage the negotiation of ecosystem water budgets, to be managed by an ecosystem trustee within each watershed. The EWBs should be used to enhance ecosystem functions as guided by the watershed ecosystem and annual watering plans. Ecosystem water should be flexibly managed, traded, and stored in surface reservoirs and aquifers.

These three reforms—better accounting, better preparation, and the establishment of ecosystem water budgets—can provide more effective and efficient use of water to support ecosystems while reducing uncertainty for water users and reducing tensions. Done well, these reforms can enable the environment to become a partner in water management rather than a constraint.

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