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A New Approach to Accounting for Environmental Water

Insights from the Sacramento–San Joaquin Delta

Cover photo courtesy of Carson Jeffres.

SUMMARY

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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.

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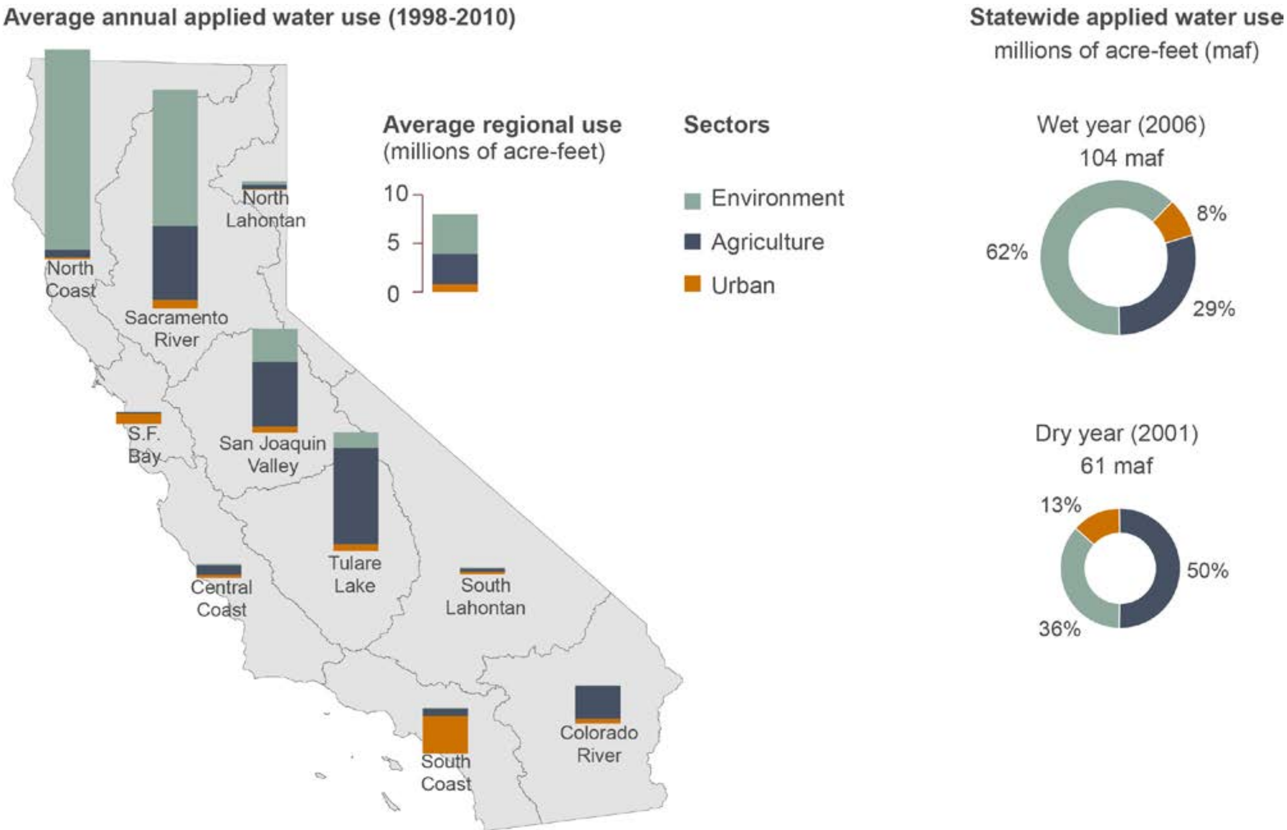
[1] In prior years, the estimates were for "normalized" use—the assumed use under normal rather than wet or dry hydrologic conditions.
[2] In some cases, these designations occurred after some dams were constructed, or are confined to stretches of rivers upstream of dams—the case for upstream stretches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

[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

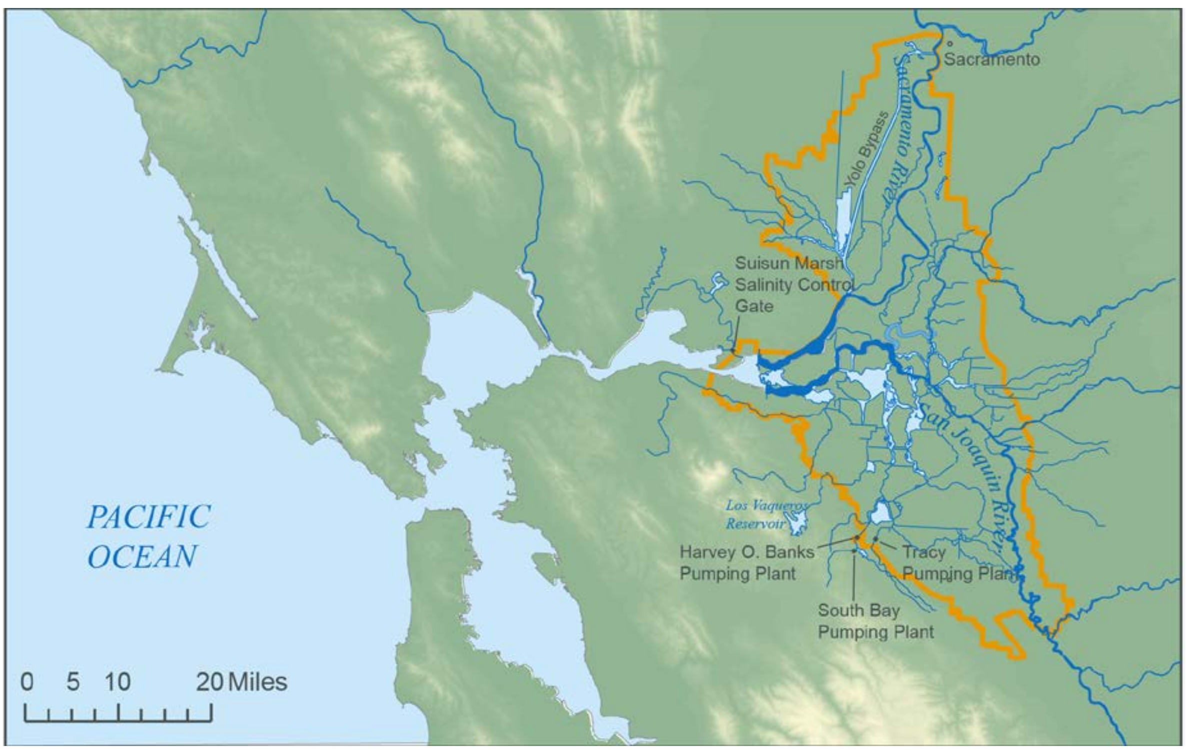
[5] The exception to multiple benefits of system water is where the water creates harm to ecosystems. Examples include releases of water from reservoirs that is too warm or nutrient rich, or releases that are out of phase with life cycles of freshwater species. Many hydropower reservoirs release pulses 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.

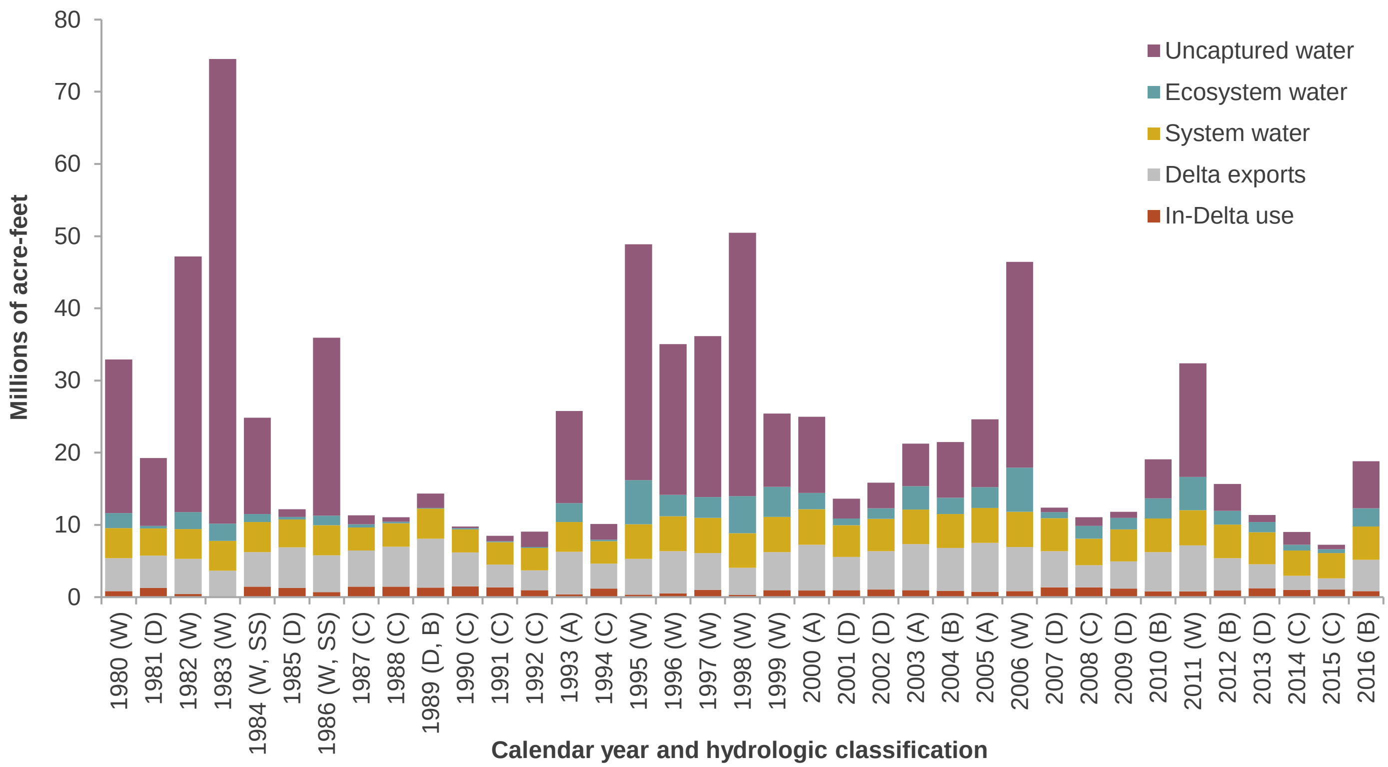
[10] Exports in 1989 were nearly as high, even though this was a dry year in the midst of a prolonged drought.

[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

[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

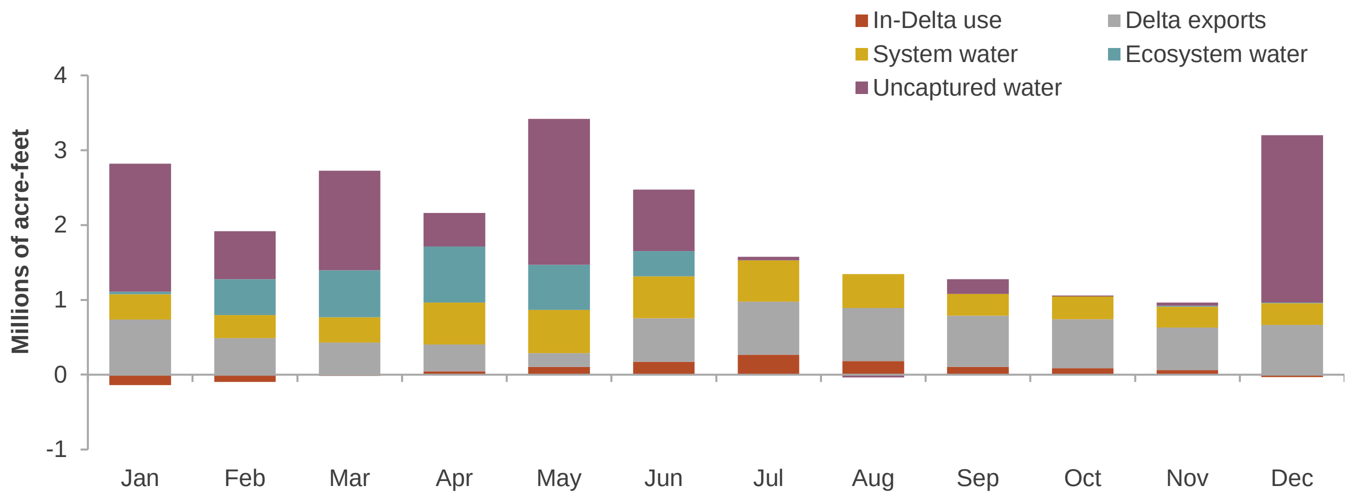
In all years analyzed for this study, there are periods when inflows to the Delta exceed the demand for water or the capacity to divert it. This uncaptured water occurs most often during the winter when upstream reservoirs are required to release storm water to maintain their flood control reserve, or 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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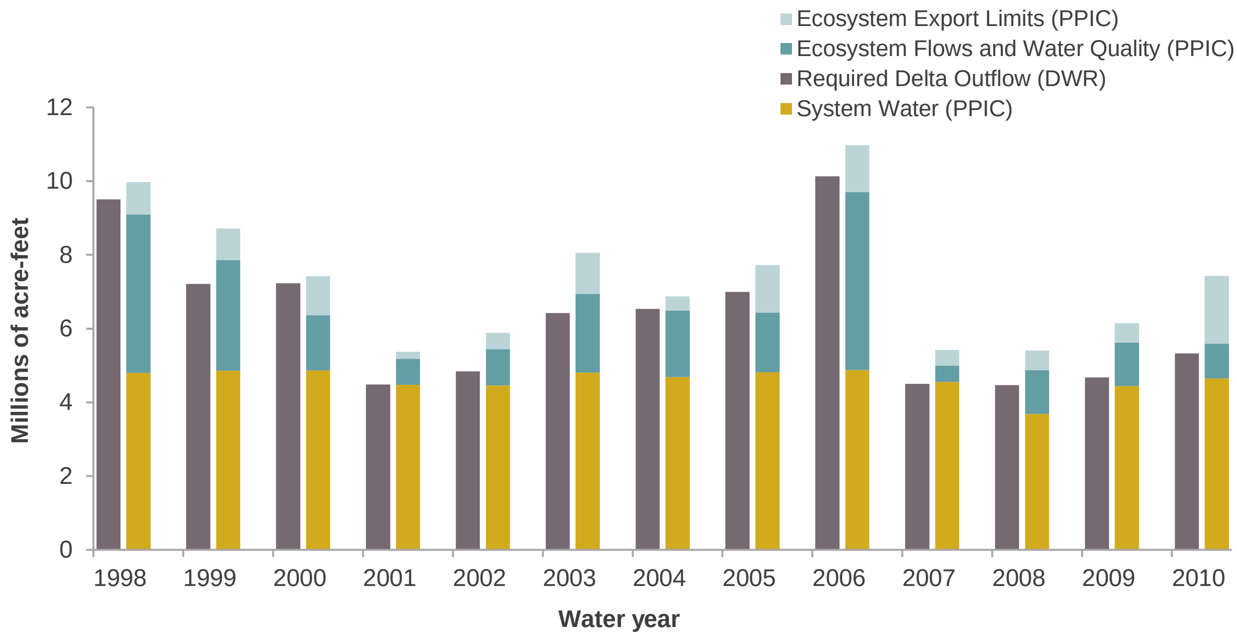
[19] Fleenor et al. (2008) show that a one foot increase in sea level rise relative to 1981–2000 conditions—a level within the range expected by the mid-21st century—could require increases in outflow of 475,000 acre-feet to maintain system water salinity standards. MacWilliams et al. (2016) show that 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

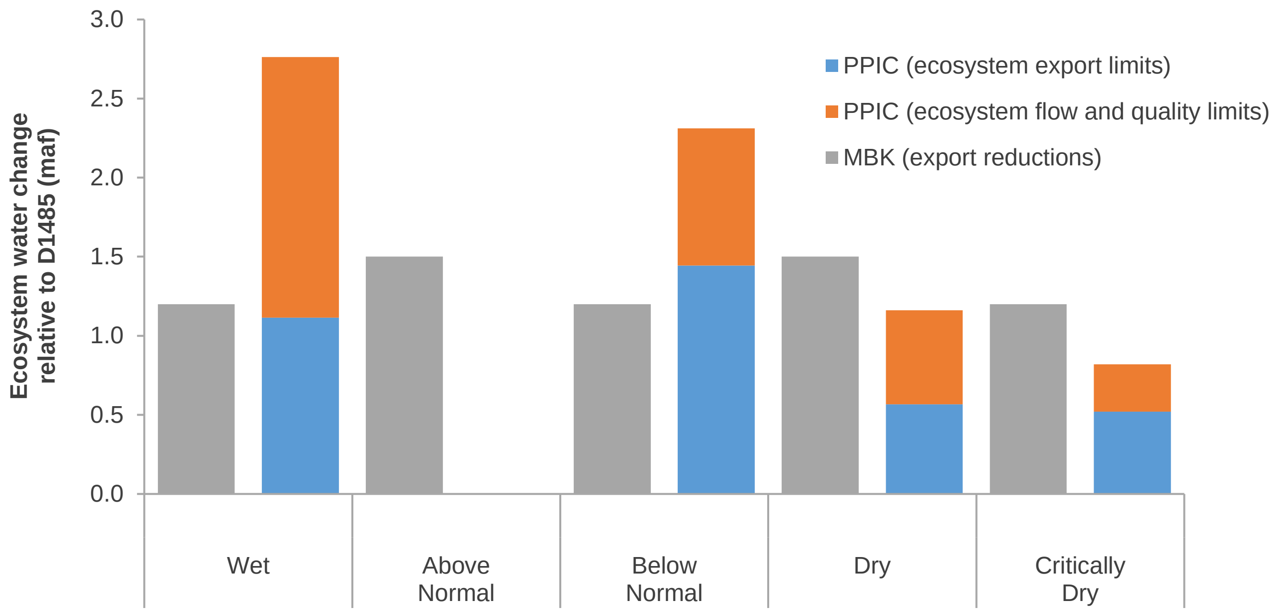
[22] There are two other main differences in DWR's methods relative to ours. First, in calculating the X2 requirements for fish, DWR's method results in slightly higher ecosystem water than is required by regulation, because it does not include carryover days. (Under X2 requirements, if the number of 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,

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[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.

REFERENCES

California Department of Water Resources. 2013. *California Water Plan Update (Bulletin 160-13)*. California Natural Resources Agency.

Cloern, James, Jane Kay, Wim Kimmerer, Jeffrey Mount, Peter Moyle, and Anke Mueller-Solger. 2017. "Water Wasted to the Sea?" *San Francisco Estuary and Watershed Science* 15 (2).

Escriva-Bou, Alvar, Henry McCann, Ellen Hanak, Jay Lund, and Brian Gray. 2016. *Accounting for California's Water*. Public Policy Institute of California.

Fleenor, William, Ellen Hanak, Jay Lund, and Jeffrey Mount. 2008. *Delta Hydrodynamics and Water Conditions with Future Conditions*. Appendix C of Jay Lund et al. *Comparing Futures for the Sacramento–San Joaquin Delta*. Public Policy Institute of California.

Hanak, Ellen, Jay Lund, Ariel Dinar, Brian Gray, Richard Howitt, Jeffrey Mount, Peter Moyle, and Barton "Buzz" Thompson. 2011. *Managing California's Water: From Conflict to Reconciliation.* Public Policy Institute of California.

Hanak, Ellen, Jeffrey Mount, Caitrin Chappelle, Jay Lund, Josué Medellín-Azuara, Peter Moyle, and Nathaniel Seavy. 2015. *What If California's Drought Continues?* Public Policy Institute of California.

Luoma Samuel, Clifford Dahm, Michael Healey, and Johnnie Moore. 2015. "Challenges Facing the Sacramento–San Joaquin Delta: Complex, Chaotic, or Simply Cantankerous?" *San Francisco Estuary and Watershed Science* 13 (3).

MacWilliams, Michael, Eli Ateljevich, Stephen Monismith, and Chris Enright. 2016. "An Overview of Multi-Dimensional Models of the Sacramento–San Joaquin Delta." *San Francisco Estuary and Watershed Science* 14(4).

MBK Engineers and HDR. 2013. *Retrospective Analysis of Changed Central Valley Project and State Water Project Conditions Due to Changes in Delta Regulations*.

Mount, Jeffrey, Brian Gray, Caitrin Chappelle, Jane Doolan, Ted Grantham, Nat Seavy. 2016. *Managing Water for the Environment During Drought: Lessons from Victoria, Australia.* Public Policy Institute of California.

Mount, Jeffrey, Caitrin Chappelle, Brian Gray, Ellen Hanak, Jay Lund, James Cloern, William Fleenor, Wim Kimmerer, Peter. 2016. *California's Water: The Sacramento–San Joaquin Delta.* Public Policy Institute of California.

Mount, Jeffrey, Brian Gray, Caitrin Chappelle, Greg Gartrell, Ted Grantham, Peter Moyle, Nathaniel Seavy, Leon Szeptycki, and Barton "Buzz" Thompson. 2017. *Managing California's Freshwater Ecosystems: Lessons from the 2012–16 Drought*. Public Policy Institute of California.

Moyle, Peter, William Bennett, John Durand, William Fleenor, Brian Gray, Ellen Hanak, Jay Lund, and Jeffrey Mount. 2012. *Where the Wild Things Aren't: Making the Delta a Better Place for Native Species*. Public Policy Institute of California.

Moyle, Peter, Larry Brown, John Durand, and James Hobbs. 2016. "Delta Smelt: Life History and Decline of a Once Abundant Species in the San Francisco Estuary." *San Francisco Estuary and Watershed Science* 14 (2).

Pitzer, Gary. 2014. *Finding the Right Balance: Managing Delta Salinity in Drought.* Water Education Foundation.

Sommer, Theodore, Chuck Armor, Randall Baxter, Richard Breuer, Larry Brown, Michael Chotkowski, Steven Culberson, Fred Feyrer, Marty Gingras, Bruce Herbold, Wim Kimmerer, Anke Mueller-Solger, Matthew Nobriga, and Kelly Souza. 2007. "The Collapse of Pelagic Fishes in the Upper San Francisco Estuary." *Fisheries* 32: 270–277.

Strum, K. M., M. E. Reiter, C. A. Hartman, M. N. Iglecia, T. R. Kelsey, and C. M. Hickey. 2013. "Winter Management of California's Rice Fields to Maximize Waterbird Habitat and Minimize Water Use." *Agriculture, Ecosystems & Environment* 179: 116-124.

Sunding, D. 2017. *Economic Analysis of Sequential Species Protection and Water Quality Regulations in the Delta*. The Brattle Group.

Winder, Monica, Allan Jassby, and Ralph Mac Nally. 2011. "Synergies Between Climate Anomalies and Hydrologic Alterations Facilitate Estuarine Biotic Invasions." *Ecology Letters* doi: 10.1111/j.1461-0248.2011.01635.x

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