PUBLIC POLICY INSTITUTE OF CALIFORNIA

A New Approach to Accounting for Environmental Water

Insights from the Sacramento–San Joaquin Delta

Technical Appendices

CONTENTS

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Appendix A

Introduction

In this appendix, we review the history of the water quality and flow standards that have governed the impoundment and diversion of water from the Sacramento–San Joaquin River and Delta system. Although most of the responsibility for complying with these standards falls on the two largest water-right holders—the federal Central Valley Project (CVP) and the California State Water Project (SWP)—this history begins well before their creation. It includes the early development of irrigated agriculture in the Delta and upstream in the Sacramento and San Joaquin River basins. It incorporates the design and operation of the two great water projects. And it concludes with the modern era of ecological protection and multifaceted water quality administration.

Pre-Project Water Quality Issues

Delta water salinity has posed challenges for water users—both within and upstream of the Delta—since the late 19th century. The Delta is an estuary.[1] Salt moves from the San Francisco Bay into the Delta with the action of the tides; fresh water from the Sacramento and San Joaquin Rivers mixes with and dilutes brackish water in the western Delta and flows into the Carquinez Strait.

All diverters of water from the Delta depend on freshwater outflows to repel saltwater intrusion. Historically, the action of the tides, coupled with low freshwater outflows during drought, would sometimes render the water too salty for domestic, manufacturing, and agricultural uses. This was especially true for water-right holders with points of diversion in the western part of the Delta and Suisun Bay, or along the Carquinez Strait itself, where tidal influences are most pronounced. Saltwater intrusion also affected upstream diverters, who might be asked to bypass sufficient flows to repel salinity from encroaching into the Delta to protect the rights of Delta riparians and senior appropriators.[2]

Salinity became an acute water quality problem in the Delta during the 1928–34 drought. Diminished snowpack, low runoff, and growing irrigation uses in the Sacramento and San Joaquin Valleys often reduced inflows into the Delta to nearly zero. These low inflows combined with in-Delta diversions to drive net Delta outflows negative during the irrigation season. As shown in Figure A1, saltwater intrusion into the Delta estuary reached unprecedented levels during this period (DWR 1962).

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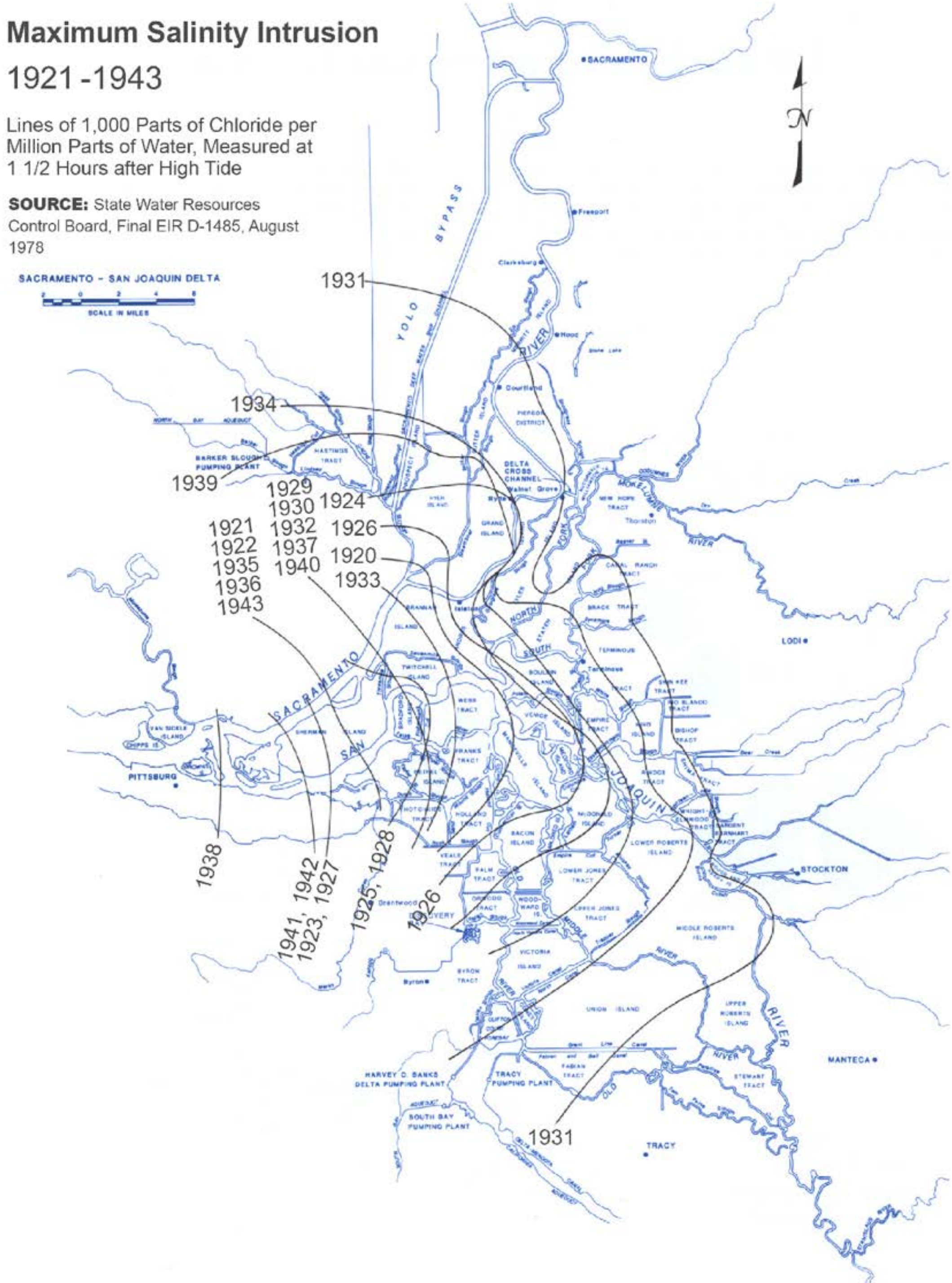
[1] "Occupying the unique zone here terrestrial, freshwater, and marine realms converge, estuaries are shaped by complex exchanges of energy, water, nutrients, sediments, and biota" (Gleason et al. 2011, p. 1). "The mixing of salt water and freshwater [sic]within an estuary generally varies with tidal action and freshwater input from river or stream discharge; salinity may periodically be higher than that of the open ocean due to evaporation. A defining feature of estuaries is the influence of dynamic forces—including tides, precipitation, freshwater runoff, evaporation, and wind—that affect the exchange of organisms, detritus, nutrients, toxins, and sediments across the land-sea boundary" (Ibid., p. 4).

[2] In 1922, the California Supreme Court held that the Town of Antioch could not compel junior appropriators along the Sacramento River to stop diverting water during periods of low water flow to protect the city's water quality rights. The court ruled that Antioch's point of diversion along the Carquinez Strait was unreasonable because the city's senior appropriative rights could be fulfilled only by requiring "practically the entire river flowing down to [its] pump so as to keep the salt water therefrom." This was contrary to "the policy of our law, which undoubtedly favors in every possible manner the use of the waters of the streams for the purpose of irrigating the lands of the state to render them fertile and productive." The court concluded that it "would be hard to conceive of a greater waste for so small a benefit" (California Supreme Court 1922). The California courts have never considered the consequences of this decision for Delta riparians and other senior appropriators whose points of diversion are further upstream within the Delta itself.

FIGURE A1

Pre-CVP maximum salinity intrusion of one part per thousand chlorides, measured at higher high tide



SOURCE: Adapted from Department of Water Resources (1995).

California's water planners recognized that controlling salinity in the Delta would be essential for future development of the state's water resources. The State Water Plan adopted in 1931 thus called for construction of a large reservoir that would capture the floodwaters from the upper Sacramento River and its principal tributaries, the McCloud and Pit Rivers, for distribution to agricultural users in the Sacramento Valley and for export to farms in the San Joaquin Valley. This reservoir (now called Lake Shasta) would also "furnish an irrigation supply without deficiency, for the present requirements in the Sacramento–San Joaquin Delta" and Carquinez Strait, and "control salinity to the lower end of the … Delta by release of water to maintain a fresh-water flow past Antioch into Suisun Bay of not less than 3,300 second-feet" (DPW 1930).

CVP and SWP Operational Water Quality

The State Water Plan formed the basis of the Central Valley Project Act, which the California Legislature enacted in 1933. The Act authorized construction of a minimum 3 million acre-feet (maf) reservoir on the Sacramento River near Kennett in Shasta County that would control the flow of the river for an array of purposes. These included flood protection, storage and diversion for irrigation and domestic use, and "salinity control in the Sacramento–San Joaquin Delta." The legislature did not specify levels of water quality or flows through the Delta, however (California Water Code §§11100–11251).

When the state was unable to sell the bonds needed to finance the project, the United States assumed responsibility for constructing and operating the CVP. The enabling legislation Congress enacted in 1935 and 1937 did not specifically mention Delta salinity control. However, Secretary of the Interior Harold Ickes' feasibility determination for the project, approved by President Roosevelt in 1935, stated: "Intrusion of salt water from the bay into the delta channels—a frequent occurrence in recent years, causing substantial loss in crops and threatening destruction of productivity—will be prevented by the released waters" (US Congress 1956a, p. 563).[3]

The storage and release of Sacramento River water for export uses in the San Joaquin Valley required that water pass through the Delta channels to the Tracy pumping station in the south Delta. The CVP Delta facilities therefore included a set of channel improvements such as the Delta Cross-Channel, which directs lower Sacramento River flows into the Delta's interior eastern channels to aid water transport to the south Delta pumps. Despite these improvements, water moving through the Delta channels remained vulnerable to saltwater intrusion. So the provision of outflows to repel salinity was an essential project function and existed independently of the US Bureau of Reclamation's (USBR) obligation to provide outflows to protect Delta water quality for the benefit of in-Delta water users.[4]

Although USBR's salinity control obligations extended both to its own contractors and to senior water-right holders, it soon recognized that these requirements were sometimes in conflict. USBR therefore decided that "the obligations of the Central Valley Project are satisfied when a satisfactory quality of water is provided at the intake to the Contra Costa and Tracy Pumping Plant" (DWR 1962, p. 64ff). This was achieved when the chloride concentration was approximately 1,000 milligrams per liter (mg/l) near False River (close to Jersey Point) on the Sacramento River, or about 3.6 mS/cm in electrical conductivity (Figure C2). That level of salinity would result in

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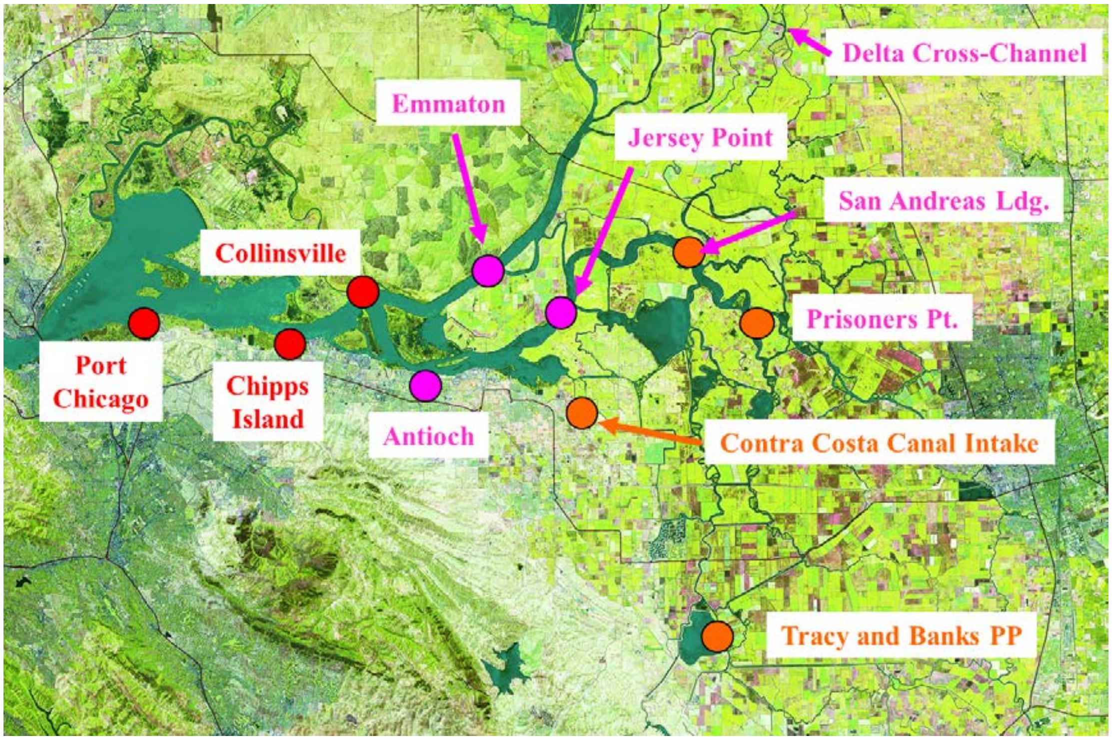
[3] A later feasibility report transmitted from Secretary of the Interior Julius Krug to President Truman in 1946 also listed salinity repulsion among the functions of the project: "The maintenance of a minimum flow of approximately 3,300 cubic feet per second at Antioch . . . is believed sufficient to prevent salinity intrusion in the Sacramento–San Joaquin delta, thereby preventing extensive crop damage as has been common in the recent past while at the same time permitting more beneficial use of lands in the affected area." In addition, the report outlined the Bureau's plans to mitigate the effects of Shasta Reservoir on salmon. These included establishment of a fish hatchery, maintenance of mid-October streamflow throughout the winter, and transfer of salmon to new spawning areas below Shasta and Keswick Dams (US Congress 1956a, pp. 586-87).

[4] The CVP Operating Plan adopted in 1952 stated: "Although it is not mentioned in the authorizing act as a project purpose, salinity control is an operational necessity. Contracts in force stipulate a limited saline content in water delivered from the delta. For the Contra Costa Canal that limit is 'not to exceed 25 parts chlorine to 100,000 parts water'" (US Congress 1956b, p. 466). In addition, the Bureau made "[s]pecific quality of water guarantees . . . in the Mendota exchange contract." (US Congress 1956b, pp. 466–67). The exchange contract stipulated that the "quality of water furnished under this contract shall be the best that the United States . . . can deliver by means of the Delta-Mendota Canal and shall be at all time suitable irrigation water for use upon the lands served by the Contracting Entities." The exchange contract then set minimum numeric criteria to implement this water quality guarantee (US Congress 1956b, pp. 608–09).
The CVP contracts for the Delta-Mendota Canal service area did not include water quality assurances. They declared that the "United States assumes no responsibility with respect to the quality of water to be furnished pursuant to this contract, and the United States does not warrant the quality of any such water." The contracts did provide, however, that the Delta-Mendota contractors would not be obligated to accept water that exceeded 300 ppm chloride (US Congress 1956b, p. 114).

approximately 350 mg/l chloride at the Contra Costa Canal intake at Rock Slough and about 1,000 mS/cm (250 mg/l chloride) at the Tracy pumping plant, based on the relationships in salinity among those locations (Denton & Sullivan 1993). These salinity targets became the *de facto* salinity standards for CVP operations.

FIGURE A2

Locations of key water quality regulations



NOTES: As described in the text, Jersey Point was an early location for regulatory compliance with the salinity standards. The SWRCB included the various locations shown here as monitoring and compliance points for the water quality standards it adopted in Decisions 1485 and 1641, described below.

In 1961, the State Water Rights Board (the predecessor to the State Water Resources Control Board [SWRCB], created in 1967) issued Decision 990, which granted water rights permits for the CVP. The board reviewed the project's history and observed:

> It is clear that protection of the Delta from salinity incursion constituted a material part of the consideration for which the State of California assigned to the United States the applications which it had filed to provide adequate water for the Project. This protection was intended to accomplish two purposes: first, to provide the agricultural lands in the Delta with water of a quality suitable for irrigation; and second, to provide a reasonably accessible source of supply to meet the industrial and agricultural requirements along the south shore of Suisun Bay [i.e., the Carquinez Strait] in Contra Costa County.

The board noted USBR's contention that "its only obligation is to provide to its contract customers water of suitable quality at the intakes of the Delta-Mendota and Contra Costa Canals." It concluded, however, that "there is no impending emergency requiring imposition of specific permit terms relative to salinity control at this time."

Instead, the board reserved jurisdiction to afford USBR, the state, and the water users in the Delta “an opportunity to work out their problems by mutual agreement” (SWRB 1961, pp. 43–58).[5]

In 1965, USBR, DWR, the Sacramento River and Delta Water Association, and the San Joaquin Water Rights Committee agreed to recognize the “Tracy Standards” as the comprehensive water quality criteria for the Delta. Two years later, the State Water Rights Board issued Decision 1275 granting water rights permits for the SWP. In its decision, the board required the SWP to comply with the Tracy Standards (SWRB 1967a, pp. 18–20).[6]

The Tracy standards established an operational baseline for water quality in the Delta. These standards became surrogates for the projects’ water quality obligations to in-Delta users, and they served as a benchmark to measure the costs to the projects of providing the requisite Delta outflow to repel saltwater intrusion. As shown in Figure A3, the projects’ adherence to the standards significantly reduced the extent of saltwater intrusion into the estuary.

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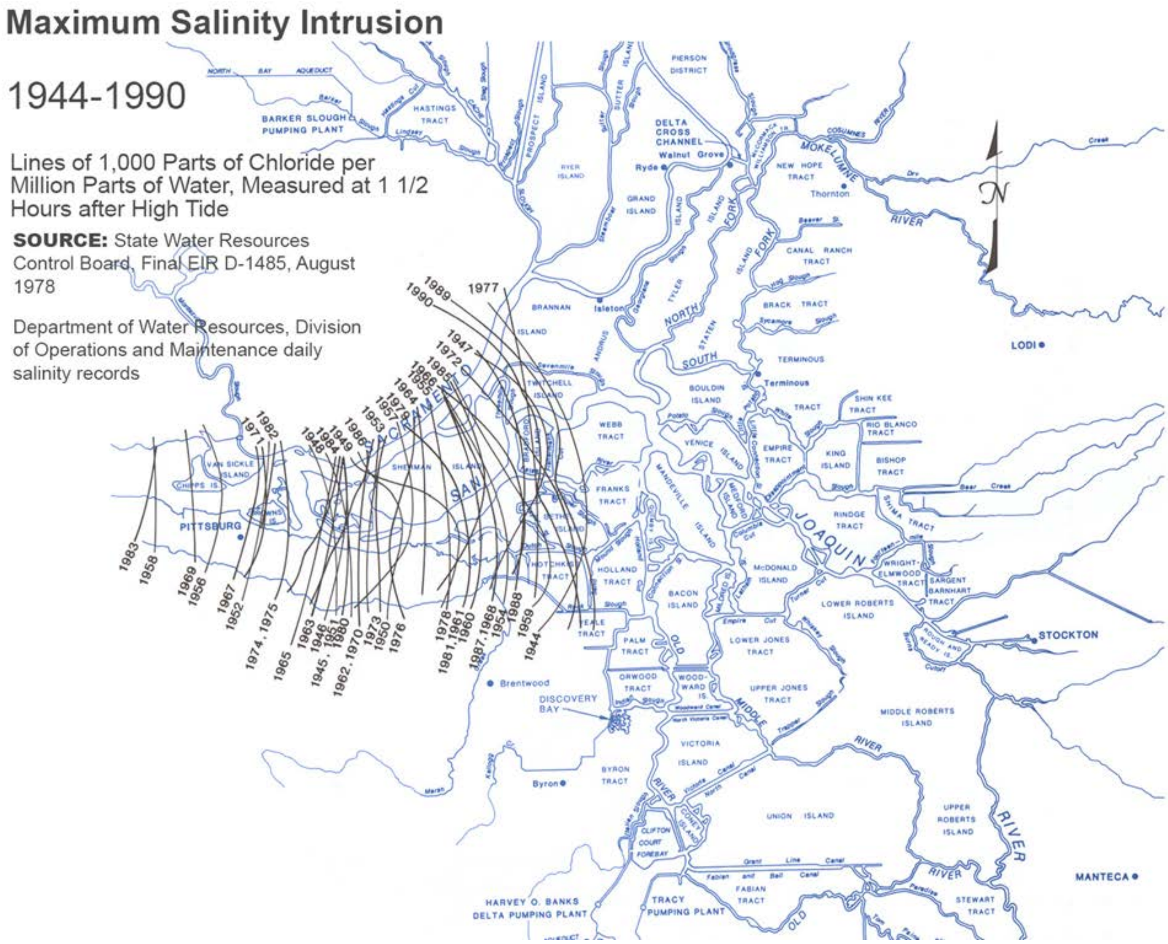
[5] The board did reject a proposal by some in-Delta water users to require the CVP “to provide a hydraulic barrier of fresh water to be maintained in the vicinity of the City of Antioch.” The board concluded that this would constitute a waste and unreasonable use of water, given the high volumes that it would require and the reasonable water supply needs of upstream and export users. It conditioned its decision, however, on the proviso that “the western portion of the Delta will be supplied by an alternate method and thereby conserve water to be beneficially used in the future through the State water facilities or the Central Valley Project” (SWRB 1961, p. 56).

[6] As it had done in Decision 990, the board acknowledged that “sufficient information is not available to finally determine the terms and conditions regarding water quality in the Delta which will reasonably protect vested rights without resulting in waste of water.” It therefore reserved jurisdiction to set new water quality standards at a later date and to apply those standard jointly to the CVP and SWP (SWRCB 1967a, pp. 17–18). The board made several minor amendments to D1275 in Decision 1291 (SWRB 1967b).

FIGURE A3
Post-CVP maximum salinity intrusion one part per thousand chlorides, measured at higher high tide



SOURCE: Adapted from Department of Water Resources (1995).

Water Right Decision 1379 (1971)

In 1971, the State Water Board exercised its reserved jurisdiction and set new Delta water quality standards to govern CVP and SWP operations. These standards included protection of fish and wildlife. Decision 1379 (D1379) modified the CVP and SWP permits in several important ways.

First, D1379 created separate salinity standards to protect in-Delta agriculture and municipal and industrial (M&I) uses. The agricultural standards included a standard of 1000 mg/l chloride concentration from April through December at Blind Point on Jersey Island and a more stringent level of 350 mg/l chloride from April through July in most years. The principal M&I standard was set at the Contra Costa Canal intake and limited salinity concentrations to no more than 250 mg/l chloride, with a 100 mg/l maximum for at least 65 percent of the year, measured over a mean tidal cycle (SWRCB 1971a, pp. 21–25 and 53–54).[7]

Second, the decision established the first water quality and operational standards for the protection of Delta fisheries. These included a salinity standard of 1.5 mS/cm at Antioch and 0.55 mS/cm at Prisoners Point for five weeks in the spring, beginning when water temperatures reached 60° F at Antioch, and a maximum 14-day mean

[7] D1379 also set salinity standards for M&I uses at Antioch, but these were suspended “when existing industrial and municipal uses are fully supplied by an overland supply”—i.e., by the Contra Costa Canal (SWRCB 1971a, p. 54).

4,000 mg/l chloride concentration at Chipps Island for the entire year (equivalent to about 12.5 mS/cm). The purpose of this standard was to protect *Neomysis awatschensis*, a tiny shrimp that is food for the striped bass.[8] In addition, export pumping was to be "minimized" from April 25 through May 31 to minimize the loss of striped bass eggs and larvae. No specific pumping level was required, but the board required the projects to provide an annual plan describing how they would minimize such harm (SWRCB 1971a, pp. 32–34 and 56–57).

To protect salmonids, D1379 required the CVP and SWP to provide a positive downstream flow in "all principal channels" of the Delta, including the Sacramento below the proposed Peripheral Canal Intake and the San Joaquin River from the head of Old River to Antioch. It also required the projects to design and operate their facilities "to minimize interference with downstream migrant salmon and steelhead" and to employ "reasonable measures undertaken to salvage those diverted by project works." A "reasonable objective," the board stated, would be "to salvage 95% of the salmon and steelhead approaching salvage facilities" (SWRCB 1971a, pp. 56–57).

Third, the board prohibited the projects from operating the south Delta pumps to cause reverse flows in the lower San Joaquin River. After DWR complained that it was not possible to prevent reverse flows from September through November without a "cross-Delta transfer facility" (i.e., a peripheral canal), the board allowed the projects to meet that requirement "to the best of their ability with the facilities available" (SWRCB 1971b, p. 4).

Finally, the board ordered USBR to comply with these new standards, altering the long-standing practice of "voluntary" federal compliance with state water quality requirements. The United States sued, claiming that the board had no authority to impose these standards on USBR. Decision 1379 was stayed pending the outcome of the litigation, and in 1978 the SWRCB replaced it with Decision 1485 (D1485) (California Court of Appeal 1986).[9]

Water Right Decision 1485 (1978)

In promulgating Decision 1485 the SWRCB acted pursuant to its integrated authority to establish water quality standards for the Delta and to assign responsibility to meet those standards on water-right holders that impound or divert water from the Sacramento–San Joaquin River and Delta system.[10] As in D1379, however, the board chose to limit responsibility for achieving the water quality standards to the CVP and SWP.

Decision 1485 imposed water quality and flow requirements the projects could meet either by reducing pumping in the Delta or by releasing water from upstream reservoirs (including bypassing flows and releasing water from storage). As with its predecessor, D1485 also included salinity protections for striped bass and salmon, but added outflow measures as well. Although D1485 assigned water to protect these fisheries, the water quality and flow standards were established in a way that they seldom interfered with the delivery capabilities of the CVP and SWP.

D1485 M&I Standards

D1485 established new M&I water quality requirements, but at a level that required less outflow than D1379. The year-round 250 mg/l chloride concentration at the Contra Costa Canal intake remained in place, but the board deleted the D1379 100 mg/l chloride level for 65 percent of the year at the Contra Costa Canal intake. Under D1485, the 250 mg/l chloride standard had to be met at the Delta drinking water intakes: Cache Slough for the City of Vallejo, the Contra Costa Canal intake, the Tracy Pumping Plant, and the Clifton Court Forebay intake

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[8] The latter was believed to be achievable with about 2,000 cfs outflow, less than half what we now estimate as necessary, and thus was not seen at the time to be burdensome to CVP and SWP deliveries. This was generally the case for the water quality standards and outflow estimates established at the time (DWR 1962).

[9] For a description of the litigation, see Jackson & Patterson (1977), at 110–14.

[10] The SWRCB's water quality authority is derived from the federal Clean Water Act §303(c) and (d) and California's Porter-Cologne Water Quality Act. The state law directs the board to "establish such water quality objectives . . . as in its judgment will ensure the reasonable protection of beneficial uses" (California Water Code §13241). The statute then defines beneficial uses as including "domestic, municipal, agricultural and industrial supply; power generation; recreation; aesthetic enjoyment; navigation; and preservation and enhancement of fish, wildlife, and other aquatic resources or preserves" (*Id.* §13050(f)).

(SWRCB 1978, pp. 37–41, Table II).[11] Of these, the Contra Costa Canal intake was (and remains) the most vulnerable to saltwater intrusion; and if the salinity standard is met at that location, it is generally met at the others.[12] The Board retained this municipal water quality standard in Decision 1641 (D1641).

Decision 1485 also added a standard to protect industrial uses, mostly of paper mills.[13] The board set the industrial standard at 150 mg/l chloride concentration for a specific number of days every year. These ranged from 155 days in critically dry years to 240 days in wet years, both to be met in 14-day intervals. The standard could be met at Antioch (the location of the paper mills) or the Contra Costa Canal intake, because the canal is a secondary source of water for the paper mills (SWRCB 1978, pp. 37–41, Table II).

D1485 Agricultural Standards

In Decision 1485, the board made a significant change to the water quality standards that protect in-Delta agriculture. It replaced the April through July 350 mg/l chloride criterion set forth in D1379 with a variable set of standards that depend on water year classification. In critically dry years, the salinity criterion at Blind Point, Jersey Island was 2.2 mS/cm electrical conductivity, which provided approximately 250 mg/l chloride at the Rock Slough intake. In wetter years, the standards required lower levels of electrical conductivity. For example, the wet year criterion at Jersey Island and Emmaton on the Sacramento River was 0.45 mS/cm for the entire period April 1–August 15. This results in approximately 80 mg/l chlorides at Blind Point, and about 50 mg/l chlorides at the intake of the Contra Costa Canal. In other years (except critically dry years) the standard begins at 0.45 mS/cm and rises to higher allowable concentrations of salinity from mid- to late-June through August 15 (SWRCB 1978, pp. 37–41, Table II). These standards also were retained in D1641.

D1485 Standards for Striped Bass and Salmonids

Decision 1485 modified the D1379 water quality and flow standards for protection of striped bass and salmon to make them more compatible with the M&I and agricultural standards in dry years. The board also increased the fisheries standards in wetter years. But the new standards would have little effect, as these years were likely to have greater outflows even without the regulatory requirements. For example:

- D1485 required minimum outflows from January through May of 12,000 cfs (for at least 60 days during that period) and 10,000 cfs in wet years (measured from February through May). But the outflow standard could be reduced if subnormal snowmelt was forecasted. It also could be relaxed if CVP and SWP reservoirs were below minimum flood control storage levels. In other words, the outflow standards need not be met if it would require loss of reservoir storage.
- The 0.55 mS/cm standard at Prisoners Point, established in D1379, remained in effect. But it was changed to begin on April 1 with the start date no longer dependent on the water temperature at Antioch.

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[11] The Vallejo intake is influenced largely by local runoff, rather than salinity intrusion. Accordingly, assigned outflow is not required to meet the water quality standard at Cache Slough.

[12] For many years, there was a dispute over the compliance location at the Contra Costa Canal intake, as the diverted water was subject to other sources of salinity—especially agricultural waste discharge from Veale Tract into Rock Slough and seepage into the first four miles of the canal. Because this drainage and seepage had much lower levels of chloride ion than seawater, the dispute centered largely on the degree of harm to the CVP and SWP and how best to address the problem. (DWR wanted to move the compliance location to Old River.) The issue was finally resolved as part of the CALFED Record of Decision (ROD), negotiated among federal and state agencies, water users, and environmental groups starting in the mid-1990s with the Bay-Delta Accord and concluding with the ROD in 2000. CALFED (USBR, DWR, USFWS, NMFS, CDFW, EPA) was formed to better coordinate regulatory actions and operations in the Delta in the mid-1990s. The CALFED ROD called for a number of actions, including water quality projects and the Environmental Water Account. With the help of the CALFED agencies and state bond funding, Contra Costa Water District moved the Veale Tract drain and has lined most of the intake channel to prevent seepage.

[13] The mills near Antioch held pre-1914 appropriative rights. Their main product, cardboard boxes used by canning companies in the region, would rust the cans if salt levels in the cardboard were too high. The paper mills signed a settlement agreement with DWR that requires the SWP to compensate the mill owners when they are required to use the water from the Contra Costa Canal. The State Water Board declined to change the Antioch industrial standard, however, because it concluded that the change would violate the anti-degradation policies of the Clean Water Act and SWRCB Resolution 68–16. It also retained the 150 mg/l industrial standard in D1641.

- D1379's 12.5 mS/cm (4,000 mg/l chloride) standard at Chipps Island also remained in effect under D1485, but the Board reduced it from year-round to October through May, with a relaxation in critically dry years in which there were deficiencies in project water deliveries.
- The Antioch 1.5 mS/cm standard could be increased when deliveries to the CVP and SWP were reduced (up to 25.2 mS/cm when export deliveries were reduced by 4 million acre-feet or more). Moreover, 25 mS/cm is the salinity typically present in San Pablo Bay, so this was in essence a complete relaxation of the standard. Lesser relaxations were associated with smaller deficiencies in project deliveries.
- D1485 required outflows of 14,000 cfs to benefit striped bass survival in May and June, and 10,000 cfs in July. The May and June outflows generally were met by runoff in wet years, but the July outflows often required the projects to release stored water from reservoirs. The required outflows dropped to as low as 2,900 cfs in critically dry years, which was less than required to meet the M&I and Ag water quality standards.

Decision 1485 also included operational limits on the projects to minimize entrainment of striped bass eggs, larvae, and juveniles. It limited export pumping to 3,000 cfs at both the CVP Tracy and SWP Banks Pumping Plant in May and June and to 4,600 cfs in July (SWRCB 1978, pp. 37–41, Table II).

At the time, the pumping capacities at Tracy and Banks were 4,600 cfs and 6,400 cfs respectively, so these pumping restrictions likely reduced project water deliveries in some water years. In wet years, the projects often could make up the deficiencies by pumping later into the irrigation season. In dry years, the pumping limits often had little effect on project water deliveries, because project exports would be limited by the lack of water and the operational water quality factors described above.

Finally, to aid salmon migration, D1485 required closure of the Delta Cross Channel gates when Delta outflow exceeded 12,000 cfs from January to mid-April, and for an additional 20 days from mid-April through May to prevent the diversion of striped bass larvae into the interior channels of the Delta. These operational requirements were coupled with year-round minimum flow standards in the Sacramento River at Rio Vista to assist migrating salmon. The minimum flows at Rio Vista varied by month and water year classification and ranged from 1,000 to 5,000 cfs (SWRCB 1978, pp. 37–41, Table II).

The SWRCB changed all of these fisheries protection standards in Decision 1641 at the end of the 1990s.

United States v. State Water Resources Control Board (1986)

In the 1986 *Racanelli* decision, the California Court of Appeal affirmed a Superior Court decision that declared Decision 1485 to be unlawful. The appellate court concluded that the SWRCB's methodology for setting the water quality standards was flawed for two reasons. First, the board had used the water rights of the Delta riparians as a surrogate for reasonable protection of water quality for *all* beneficial uses of Delta waters. Second, the board had set the Delta water quality standards only by reference to the quantity of water that the CVP and SWP could reasonably contribute, rather than taking a broader view that included upstream diverters, dischargers, and other stressors on the system (California Court of Appeal 1986, pp. 115–20).[14]

The court also held that federal law allowed the board to impose water quality and flow standards on the CVP, and that the board had authority under its reserved jurisdiction over CVP and SWP permits, the public trust, and the reasonable use doctrine of Article X, Section 2 of the California Constitution to ensure that the projects meet their water quality and fisheries protection obligations (California Court of Appeal 1986, pp. 127–31, 134–37, and 148–52).

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[14] The directive that the board must take a "global perspective" in revising the water quality standards has required it to consider the effects of other significant diverters—both upstream of and within the Delta—and to take into account the potential contributions of those users, along with the CVP and SWP, to the achievement of the new standards. As explained below, in Water Rights Decision 1641, the board chose to continue to assign all of the burden of meeting the revised water quality standards to the two projects. Following D1641, however, some upstream users have agreed to sell water to CVP and SWP export contractors in exchange for the projects' agreement to continue their sole responsibility to meet the Delta standards.

The court did not enjoin enforcement of D1485, however, because the board had announced that it would be revising the water quality standards and implementing water rights decisions for the Delta estuary. Following a tortuous administrative process that included several years of SWRCB hearings, the US Environmental Protection Agency's veto of the board's 1991 water quality standards, and a gubernatorial directive that the board rescind its draft revisions to D1485, the SWRCB adopted new Water Quality Control Plan in 1995 (SWRCB 1995).[15] The projects agreed to operate pursuant to the revised standards on an interim basis, pending revision of their water rights permits. The board formally incorporated the new water quality criteria into the CVP and SWP permits at the end of the decade.

Water Right Decision 1641 (1999 and 2000)

Decision 1641 was a product of the 1994 Bay-Delta Accord—a comprehensive agreement among the CVP, SWP, state and federal regulatory agencies, water users, and environmentalists—and the consequent Bay-Delta Water Quality Control Plan of 1995 (SWRCB 1995). The new standards removed almost all of the old water quality criteria for striped bass and salmonids and replaced them with flow and operational standards to protect a wide variety of species, including two species that were recently listed for protection under federal Endangered Species Act—Sacramento River winter-run Chinook salmon and the delta smelt. As noted above, the D1485 agricultural and M&I standards were unchanged in Decision 1641 (SWRCB 2000, pp. 181–82, Tables 1 and 2).[16]

D1641 Flow and X2 Standards

D1641 imposes minimum flows for fishery protection in every month. For January through June, the required salinity levels and outflow depend on the runoff on eight major streams (known as the 8-river runoff index): the Sacramento River flow at Bend Bridge, near Red Bluff; the Feather River, total inflow to Oroville Reservoir; the Yuba River flow at Smartville; the American River, total inflow to Folsom Reservoir; the Stanislaus River, total inflow to New Melones Reservoir; the Tuolumne River, total inflow to Don Pedro Reservoir; the Merced River, total inflow to Exchequer Reservoir; and the San Joaquin River, total inflow to Millerton Lake.[17] For the rest of the year (July-December), the required outflow depends on the water year classification. This classification uses a new index that relies heavily on the forecasted April-July runoff (40 percent), and to a lesser extent on the October through March runoff (30 percent) and the prior year's index (30 percent) (SWRCB 2000, pp. 183–87, Table 3).

The X2 standard requires the location of the two part per thousand salinity line to be west of certain specific locations for a specified number of days each month (specifically, Collinsville, Chipps Island, and Port Chicago at 81 km, 75 km, and 64 km respectively from the Golden Gate—see Figure C2). The number of days is determined by the 8-river runoff index of the prior month. D1641 allows "carryover" days from one month to the next if the standard is met for a greater number of days than required. The board included this to encourage more lengthy, continuous periods of low salinity consistent with the patterns of outflow found in earlier periods, rather than having the outflow fluctuate in an effort to meet the standard exactly. The number of days and location of X2 requirements are based on the location of X2 found in the late 1960s and early 1970s, when fish populations were much higher and diversions from the Delta much lower (SWRCB 2000, pp. 183–87, Table 3).

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[15] USEPA vetoed the revised water quality standards in September 1991, concluding that they were inadequate to protect Delta fisheries. The SWRCB responded with a draft Water Rights Decision 1630, which would have established more protective interim water quality and flow requirements (SWRCB 1992). Governor Pete Wilson ordered the board to withdraw the draft decision on April 1, 1993. USEPA's draft federal water quality standards may be found at 59 Fed. Reg. 810 (1994). It withdrew them following the Bay-Delta Accord of 1994 and the board's promulgation of revised water quality standards in 1995 (Rieke 1996).

[16] The State Water Board originally promulgated Decision 1641 in 1999 and revised it the following year. All citations are to the 2000 revised decision. For a graphical depiction of the seasonality of the different components of D1641, see "Bay Delta Standards."

[17] A relaxation in May and June can occur if the 4-river index (based on the runoff to the first four streams in the list) is less than 8.1 MAF; this was applied in 2014.

Because uncontrollable influences (e.g., tides, wind, and barometric pressure) can dramatically change salinity in the Delta over the short term, the X2 standard can be met in three ways: through a daily average salinity less than 2.64 mS/cm at the required location; a 14-day running average of salinity less than 2.64 mS/cm; or with outflows of at least 7,100, 11,400, or 29,200 cfs averaged over three days. The “Port Chicago” location (X2 = 64 km from the Golden Gate Bridge) must only be met in the current month if the 14-day average of electrical conductivity was less than 2ppt at this location on the last day of the prior month. This “trigger” is provided to avoid large, sudden gyrations in outflow (SWRCB 2000, pp. 183–91, Tables 3 and 4).

Other requirements include a modified Prisoners Point standard of 0.44 mS/cm for all of April and May (but suspended in May in critically dry years), and a new Rio Vista flow requirement for salmon migrations that is limited to the months of September through December, with the levels ranging from 3,000 to 4,500 cfs, determined by month and hydrologic year classification (SWRCB 2000, pp. 183–87, Table 3).

Finally, the board set minimum inflows for the San Joaquin River for February through June. For the period February 1 through April 14 and May 16 through June 30, required inflows depend on the location of the X2 requirement. For the 30-day April 15 through May 15 “pulse flow period,” higher outflows are required. D1641 also mandates fall pulse flows of 1,000 cfs plus 28 thousand acre-feet (taf) during October. These pulse flows are not to exceed a monthly average of 2,000 cfs, however, and pulse flows are not required at all in a critical year following a critical year. The starting dates for the pulse flows are allowed to change in consultation with fisheries agencies (for example, to coincide with hatchery releases or physical conditions in the river) (SWRCB 2000, pp. 183–87, Table 3).

D1641 Operational Requirements

Decision 1641 also imposes year-round export pumping limits to protect salmon and delta smelt. From February through June, pumping at Banks and Tracy are limited to 35 percent of inflow; for the rest of the year they are limited to 65 percent. In addition, export pumping is restricted to no more than the San Joaquin River inflow during the 30-day (nominal) pulse flow period from April 15 through May 15. If the San Joaquin River inflow is less than 1,500 cfs, however, the pumping can be as much as 1,500 cfs. The 30-day period also can be changed to start on other dates if determined to be best for aquatic species protection.

In addition, D1641 requires the Delta Cross-Channel gates to be closed from February 1 through May 20 to protect migrating salmon juveniles. From May 20 through June 15, they are to be closed for up to 14 days, and closed up to 45 days during November through January. In the latter two cases, closures are determined in consultation with the fisheries agencies (SWRCB 2000, pp. 183–87, Table 3).

The Central Valley Project Improvement Act, the Vernalis Adaptive Management Plan, and Endangered Species Act Requirements

The 1994 Bay-Delta Accord and 1995 Bay-Delta Plan coincided with early implementation of the Central Valley Project Improvement Act (CVPIA) and the Endangered Species Act Biological Opinions (BiOps) for protecting Sacramento River winter-run Chinook salmon and delta smelt. Under section 3406(b)(2) of the CVPIA, USBR must dedicate 800 taf[18] of CVP yield annually to fish and wildlife enhancement (including wetlands). The law specifies that the water can be used for meeting the CVP’s share of any new water quality standards for the Delta, such as D1641, or for other purposes(CVPIA 1992). Although the parties to the Accord agreed on many water quality and flow standards that have remained in place, the San Joaquin River pulse flow standards were not

[18] The 800 taf can be reduced to 600 taf in dry years (CVPIA §3406(b)(2)).

completely resolved in 1994, in part because there was continuing dispute over how best to implement them and because the issue generated opposition from water users on the San Joaquin tributaries who would be required to contribute to these flows. In 2000, they signed the Vernalis Adaptive Management Plan (VAMP). This plan required different levels of Delta inflow from the San Joaquin River and pumping reductions than contained in the 1994 Accord, to be implemented over the next 10 years.[19] At the same time, USBR decided to use some of the CVPIA "(b)(2)" water to help comply with the delta smelt BiOp, which limited project exports to 50 percent of San Joaquin River inflow, but not less than 1,500 cfs (San Joaquin River Technical Committee 2008).

The Accord called for a pulse flow and pumping reduction period of 30 days, nominally starting April 15 of each year, though the start date could be modified based upon fish monitoring. Exports were to be limited to the San Joaquin River inflow running average. The BiOps (using CVPIA (b)(2) water) called for pumping levels at half the San Joaquin River inflow (with a lower limit of 1,500 cfs). At times the fisheries agencies requested longer periods than the 30 days, using either (b)(2) water or the flexibility allowed in the Accord (when the water lost due to the pumping restrictions could be made up later).

The federal fisheries agencies later expanded the pulse flow period from 30 days to a full 60 days. The projects obtained the additional pulse flows through a combination of CVPIA (b)(2) water and the Environmental Water Account (EWA) created by the 2000 CALFED Record of Decision (CALFED 2003). Under Decision 1641, the projects retained the flexibility to reduce pumping or increase reservoir releases to meet the applicable standards and to pump later in the season to make up for earlier pumping restrictions.

In 2008, following a period of increased CVP and SWP exports and concomitant declines in Delta smelt and winter-run Chinook salmon populations, a federal court ordered the USFWS and NMFS to revise the biological opinions (Alexander 2012).

The revised biological opinions included more lengthy closures of the Delta Cross-Channel, primarily in December and January, and additional restrictions on south Delta pumping. The new pumping restrictions ran from mid-December through March, as well as in June. These restrictions were implemented by regulation of net flows in Old and Middle Rivers, which is the main route of water from the Sacramento River to the south Delta pumps. The revised BiOps also restricted pumping in April and May as a fraction of inflow from the San Joaquin River (USFWS 2009; NMFS 2009).

The agencies flexibly implemented the BiOps in 2011 for the fall X2 outflow requirement required in above normal and wet years. (This was the first year the "fall X2" outflow standard was implemented since the BiOps were revised in 2008). An outflow of 11,400 cfs (X2 at Chipps Island) was required for a period of approximately 60 days from late August to mid-October. The levels and timing took into account the desire for more outflow for delta smelt and the conflicting need for more carryover storage in Shasta to protect cold water for winter-run salmon.

The 2014 and 2015 Temporary Urgency Change Orders

In 2014 and 2015, the State Water Board authorized a variety of temporary changes to the Delta water quality and flow standards. California had been in a drought since 2012, and 2014 and 2015 were designated as "critically dry." The severity and breadth of the drought years made it extremely difficult for the CVP and SWP to meet the requirements of D1641 and the 2009 BiOps. In particular, there was grave concern that use of stored water to meet outflow requirements in the spring would deplete cold water in Shasta Reservoir to the degree that it would threaten winter-run Chinook salmon eggs and fry development. There also was a significant risk that reservoir storage would fall so low that the projects would no longer be able to control salinity in the Delta.

[19] For illuminating discussions of the development of the VAMP, see Johnston (1998) and San Joaquin River Technical Committee (2008).

In January 2014, USBR and DWR filed temporary urgency change petitions (TUCPs), asking the board to loosen Delta salinity and outflow standards and to modify several restrictions on project operations. In a series of orders, the board: (1) reduced the requirement of a minimum Delta outflow in February from 7,100 cfs to 3,000 cfs, which saved up to 0.23 maf of stored water; (2) allowed the Delta Cross-Channel gates to be open to help meet salinity control in the Delta;[20] (3) limited exports to health and safety levels (1,500 cfs) when D1641 flow and salinity standards were not being met; (4) reduced the required flow in the lower Sacramento River from September through November 15; (5) moved the compliance point for a key Delta water quality standard upstream to Three Mile Slough on the Sacramento River; and (6) reduced San Joaquin River inflow requirements in October to conserve reservoir water.

At the start of the 2015 calendar year, conditions had not substantially improved. USBR and DWR again submitted TUCPs seeking similar reductions in water quality and outflow standards as in 2014. Their primary stated goals were to retain water in project reservoirs to meet downstream flow and temperature standards and Delta water quality requirements, while also fulfilling their contractual water service obligations and supplying water for public health and safety.[21] The projects also sought greater flexibility in their operations to take advantage of storm-related inflows.

The board approved the TUCPs on February 3rd and amended them a month later to reduce impacts of project operations on Delta smelt. Throughout March, the Bureau and DWR submitted amended TUCPs to further relax salinity and outflow standards in the Delta and to increase exports. The board issued a new TUC order in April. In it, the board limited the projects' full request to relax the salinity, outflow, and pumping standards, and it raised concerns over USBR's temperature management efforts, including Shasta and New Melones Reservoirs. It also required USBR to submit a temperature management plan for approval by the board's executive director.

By spring 2015, it had become even more difficult to manage salinity in the Delta due to the accumulated depletions of reservoir storage and—in the case of Shasta and New Melones Reservoirs—the need to manage water temperatures in the Sacramento River and the lower San Joaquin and south Delta. In May, the board issued a water quality certification to DWR that allowed the construction of a rock barrier in West False River in the south Delta to reduce the amount of outflow needed to maintain salinity standards for export pumping. In July, the board extended the TUC order for the remainder of the summer and into early fall.[22]

Conclusion

Salinity control in the Delta has been a challenge for water-right holders and water managers for more than 100 years. What began as a struggle between upstream appropriators and in-Delta users over flows needed to repel saltwater intrusion has evolved to a more complex dispute over the outflow needed to protect water quality throughout the system and to provide flows to improve the abundance of native fish. As the major determinants of water flows in this system, the CVP and SWP have been charged with three overlapping water quality

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[20] The board coordinated this aspect of the TUC orders with National Marine Fisheries Service to ensure that the Delta Cross-Channel was closed when needed to protect migrating salmon.

[21] USBR has an obligation to deliver a minimum of 75 percent of the stated contract amounts to two groups of CVP contractors who held pre-project water rights. These priority contractors include the Sacramento River Water Rights Settlement contractors and the San Joaquin River Exchange Contractors. The other CVP and SWP contractors have no minimum water service rights during severe drought. In 2014 and 2015, CVP water service contractors located south of the Delta received no project water, while SWP contractors who rely on Delta exports received 5 percent of their state contractual entitlements in 2014 and 20 percent in 2015 (USBR 2016; MWD 2016).

[22] USBR and DWR operated the projects under the July TUC orders throughout the summer of 2015. The rock barriers were removed in the early fall. Then, late fall and early winter rains eased conditions more generally. Although drought contingency planning continued into 2016, no further TUCPs were submitted to the board. The SWRCB has estimated that the TUC orders increased water available for CVP and SWP exports by approximately 400,000 acre-feet in 2014 and 688,000 acre-feet in 2015 (SWRCB 2015). The low water reserves in Lake Shasta were disastrous for the winter-run Chinook salmon: 95 percent of salmon eggs and fry were lost in 2014, and 98 percent perished in 2015 (Mount et al. 2017).

responsibilities: satisfaction of the reasonable water quality needs of in-Delta diverters, assurance of the reasonable water quality needs of their own contractors, and provision of essential flows for fish and wildlife.

The third responsibility has recently been the most controversial. The regulatory assignment of water to ecological functions occurred after the projects had signed contracts for water service and begun water deliveries to their contractors. When water shortages began to increase in the CVP and SWP systems, it was easy for many to blame the environmental regulations for those supply deficiencies. Yet, as Appendix B illustrates, the assignment of water to the ecosystem is only one contributor to systemic water shortages. The largest contributor to water shortages in dry periods is the assignment of water rights beyond the ability of nature to supply the needed water, and the resulting expectation that the water associated with those rights will be available even in droughts. During the driest hydrologic conditions, the water allocated to fish and other ecological uses is much smaller than the water that must be left instream to protect water quality for in-Delta diversions and export uses.[23]

[23] In above normal and wet years, there is abundant water that is surplus to all needs (extractive and ecological), and the water rights and regulatory assignments have less significance. In these wetter periods, the water assigned to the ecosystem can be greater than the water that must be left instream as outflow to protect water quality for in-Delta diverters and exports. But it has much less effect on diversions and deliveries due to the vast amount of water available for all. See Appendix B.

REFERENCES

Alexander, Kristina. 2012. *Biological Opinions for the Sacramento–San Joaquin Delta: A Case Law Summary.* Congressional Research Service.

CALFED Bay-Delta Program. 2003. *The Environmental Water Account: Reducing Conflict Between Fishery Management and Water Supply.* California Resources Agency.

California Court of Appeal. 1986. *United States v. State Water Resources Control Board.* 182 Cal. App. 3d 82.

California Supreme Court. 1922. *Town of Antioch v. Williams Irrigation District*. 188 Cal. 451.

California Central Valley Project Act. California Water Code §§11100 et seq.

California Porter-Cologne Water Quality Act. California Water Code §§13000 et seq.

Central Valley Project Improvement Act. 1992. Public Law No. 102-575, §§3401-3412.

Denton, Richard, and Greg Sullivan. 1993. *Antecedent Flow-Salinity Relations: Application to Delta Planning Models.* Contra Costa Water District.

Department of Public Works, Division of Water Resources. 1930. *Report to the Legislature on the State Water Plan.* Bulletin 25.

Department of Water Resources. 1962. *Salinity Incursion and Water Resources.* Bulletin 76. Appendix, page 108, Table 22 and Plates 12 and 15.

Department of Water Resources. 1995. *Delta Atlas*.

Gleason, M.G., S. Newkirk, M.S. Merrifield, J. Howard, R. Cox, M. Webb, J. Koepcke, B. Stranko, B. Taylor, M.W. Beck, R. Fuller, P. Dye, D. Van der Schaaf, J. Carter. 2011. *A Conservation Assessment of West Coast (USA) Estuaries*. The Nature Conservancy.

Jackson, W. Turrentine, and Alan Patterson. 1977. *The Sacramento–San Joaquin Delta, The Evolution and Implementation of Water Policy.* California Water Resources Center, University of California, Davis.

Johnston, William. 1998. *The San Joaquin River Agreement and the Vernalis Adaptive Management Plan.* Proceedings of the USCID Conference on Shared Rivers, United States Conference on Irrigation and Drainage.

Metropolitan Water District of Southern California. 2016. *MWD Water Sales and State Water Project Water Conditions: 1990 to 2015.*

National Marine Fisheries Service. 2009. *Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project. Department of Commerce.* .

National Marine Fisheries Service. 2011. *Amendments to the Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project. Department of Commerce.*

Rieke, Elizabeth. 1996. "The Bay-Delta Accord: A Stride Toward Sustainability." *University of Colorado Law Review* 67 (2) 341–69.

San Joaquin River Technical Committee. 2008. *Summary Report of the Vernalis Adaptive Management Plan (VAMP) for 2000-2008.* Delta Science Program.

State Water Resources Control Board. 1971a. *Decision 1379: Delta Water Rights Decision.*

State Water Resources Control Board. 1971b. *Order Denying Reconsideration of and Clarifying and Correcting Decision 1379.*

State Water Resources Control Board. 1978. *Water Right Decision 1485: Sacramento–San Joaquin Delta and Suisun Marsh.*

State Water Resources Control Board. 1992. *Draft Water Right Decision 1630: San Francisco Bay/Sacramento–San Joaquin Delta Estuary.*

State Water Resources Control Board. 1995. *Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary.* State Water Resources Control Board. 2000. *Water Right Decision 1641: Implementation of Water Quality Objectives for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary.*

State Water Resources Control Board. 2015. *Public Workshop: Drought Activities in the Bay-Delta.* State Water Rights Board. 1961. *Water Right Decision 990.*

State Water Rights Board. 1967a. *Water Right Decision 1275.*

State Water Rights Board. 1967b. *Water Right Decision 1291.*

US Bureau of Reclamation. 2016. *Summary of Water Supply Operations.*

US Congress. 1956a. *Central Valley Project Documents, Part One, Authorizing Documents*. H. Doc. 416, Pt. 1, 84th Cong., 2d Sess.

US Fish and Wildlife Service. 2009. *Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project and State Water Project.*

Appendix B

Introduction

The allocation of scarce water to meet competing objectives is a major challenge for water managers in California, particularly during droughts. Water scarcity is common in all but the wettest years, forcing difficult tradeoffs between using water in businesses and homes, versus leaving water in reservoirs, rivers, wetlands, and aquifers to support ecosystems and to prepare for future dry years.

During the recent drought (2012–16), controversy was particularly acute in the Sacramento–San Joaquin Delta, where extreme water scarcity affected all water users, including freshwater ecosystems. Debate often centered on regulations that set water quality and flow standards or that limited pumping from the Delta. Meeting these regulations limited the amount of water available for export from the Central Valley Project (CVP) and the State Water Project (SWP). In the driest years, even some of the most senior water-right holders were affected by cutbacks in supplies.

This technical appendix accompanies a report that recommends new approaches to accounting for water used to meet environmental goals, using environmental allocations in the Sacramento–San Joaquin Delta as a case study (Gartrell et al. 2017). Technical Appendix A reviews the laws and regulations that assign water flowing into the Delta to various purposes, including protection of water quality for in-Delta agricultural and municipal and industrial (M&I) uses and Delta exports (collectively referred to here as "system water"), and protection of water quality and flows for ecological uses ("ecosystem water"). Here, we estimate the outflow needed to meet these regulations, along with water diverted for in-Delta and export uses ("water diversions"), and water that exceeds these demands and regulatory requirements ("uncaptured water"). We describe methods for translating water quality requirements into water flow requirements, along with the challenges and uncertainties associated with the methodology chosen. We examine the period 1980–2016, a time during which significant regulatory changes affected the apportionment of Delta inflows. We also suggest how the approach used here can be made part of improved accounting to better manage Delta water supplies and to create a common understanding about how this water is used. While the focus is on the apportionment of inflows into the Delta, we also provide a comparison with the overall flows in the Sacramento and San Joaquin River watershed, to put the Delta water balance in perspective with the overall watershed water balance.

We first describe the approach used for apportioning Delta inflows into its various uses. We then discuss caveats and limitations of the analysis and present key results. A discussion section describes major lessons from this new approach to environmental water accounting. All data assembled for this study, along with the sources and methods used, are detailed in the accompanying data set *PPIC Delta Water Accounting*.

Methodology for Apportioning Delta Inflows

In addition to flood control, management of freshwater inflows to the Delta seeks to support three general, often competing objectives: (1) diversion by water-right holders for agricultural, domestic, and commercial uses in and near the Delta; (2) exports by the CVP and SWP to farms and cities outside of the Delta; and (3) Delta ecosystem health, including the protection of fish species listed under federal and state Endangered Species Acts (ESAs). To achieve these objectives, a mix of federal and state regulations set flow and water quality standards that vary depending upon location within the Delta, time of year, and hydrologic classification of the water year. Regulations also control the timing and volume of export pumping at CVP and SWP facilities for ecosystem protection.

The net effect of these regulations is to apportion Delta inflows into water that must be left in place to protect water users (system water) and the Delta ecosystem (ecosystem water), and water that may lawfully be diverted for farms and cities within and around the Delta and in export regions (water diversions). The water that must be left in place is sometimes referred to as water "dedicated" to the environment. Here, we generally use the terms "assigned water" or "assigned flow" to refer this water, which must leave the Delta as outflow to the ocean to meet regulatory requirements.[24] We also track an additional category of outflows—uncaptured water—which occur when inflows into the Delta exceed system and ecosystem water, as well as the diversion capacity or demand of in-Delta users and exporters. Uncaptured water is most significant in wetter years, but it occurs in some months during dry years as well.

The estimates presented here focus on flows that reached the Delta for the period 1980–2016. Later, we examine how water was apportioned throughout the entire Sacramento and San Joaquin River watershed for the period 1995–2015, including flows that did not reach the Delta because of upstream diversion and use.

Characterizing and Assigning Flows

The proper characterization of the water assigned to comply with water quality and flow standards is a complex and somewhat subjective endeavor. Most inflows to the Delta serve multiple purposes. For example, if a minimum outflow for fish and wildlife is sufficient to also meet water quality standards to protect municipal and industrial (M&I) uses, to which category should the water be assigned? Both in-Delta and export users require low salinities in the Delta so that the water is suitable for irrigation and M&I uses. The projects often release water from upstream reservoirs to help keep Delta salinity low, pushing back saltwater that is carried into the Delta by the tides. These releases—which result in large outflow volumes—help meet water quality standards for agricultural and M&I users, but also provide benefits to the ecosystem. Conversely, salinity and outflow standards to protect ESA-listed species such as delta smelt constrain Delta exports, but the improvements in water quality from these standards also benefit in-Delta and export users by helping them meet their own water quality needs.[25]

This study takes a building block approach to the assignment of regulatory water. First, we accounted for the assigned water for each of the various uses; next we determined the assigned water for any day resulting from the combination of applicable regulations. From there, we determined the amount required to protect water quality for export and in-Delta uses (system water), and the additional water required to support the ecosystem (ecosystem water). This building block approach assigns regulatory flows based on the historical order of water use. We recognize that there is always some system water that serves ecosystem purposes as well, but this water would be required to support diversions even if there were no ecosystem management objectives in the Delta. Later we show how this multipurpose water—which meets both system and ecosystem requirements—fits into the overall water balance.[26]

The sources and methods used to apportion Delta inflows among these categories are summarized in Table B1 and discussed in detail below and in *PPIC Delta Water Accounting*. As an illustration of the approach, Figure B1 provides an overview of the monthly share of inflow apportioned to the major categories described above for 2005 (an above-normal water year) and 2013 (a dry year).

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[24] In choosing the term "assigned," we are avoiding other possible terms such as "allocated," which is commonly used in describing the amount of water available to contractors of the SWP and CVP. Allocated in that sense implies that water is available, but not necessarily taken (it can be returned to the projects, reassigned to other users, or held and taken at a later time).

[25] As described in the main report (Gartrell et al. 2017) and in the discussion below, water accounting by the California Department of Water Resources in the California Water Plan Updates (Bulletin 160) does not distinguish between system and ecosystem water, assigning all of this outflow to the environment as "required Delta outflow." This masks, and perhaps fuels misperceptions of, the multiple uses and benefits of this regulatory water.

[26] The data set *PPIC Delta Water Accounting* also present alternative ways of categorizing system, ecosystem, and multipurpose water.

Our important caveat to note at the outset is that our method of assigning water for system and ecosystem needs often overstates the cost of these regulations in terms of reduced Delta exports, particularly in relatively wet years. When there is uncaptured outflow, the water required to meet salinity and flow standards often does not pose tradeoffs with exports because there is more than enough water to meet all needs. In contrast, ecosystem regulations that limit export pumping can reduce export deliveries even when there is uncaptured water. We describe these issues in greater detail below, and show how our method compares with a method used to estimate the cost of regulations to Delta exports (MBK Engineers and HDR 2013).

TABLE B1

Components of Delta inflow

Category	Definition	Data source or method of calculation
I. Delta diversions	Water diverted for M&I and agricultural use within and around the Delta and in export regions	See each subcategory
In-Delta use	Consumptive use in the Delta consisting of channel evaporation, seepage and diversions to Delta islands and uplands, smaller Delta diversions, and diversions by the Contra Costa Water District (CCWD) and North Bay Aqueduct (NBA), minus return flows and precipitation in the Delta.[(a)]	DICU ([b]) CDEC [(c)] Dayflow [(d)]
Delta exports	Diversions from the Banks and Jones pumping plants in the South Delta, for delivery to State Water Project and Central Valley Project contractors south of the Delta.	Dayflow, CDEC
II. System water	Water assigned to protect the quality of Delta diversions. These flows may also provide ecosystem benefits, but they would be required even without regulations to protect the ecosystem.	See each subcategory.
Export water quality (Tracy standard)	Outflow needed to maintain water quality sufficient for exports at the Banks and Jones pumping plants (250 mg/l chloride and 1 mS/cm).	Determined through G-Model relationships (Denton 1993)[(e)]
M&I and agricultural Delta water quality standards under D1485 and D1641	Outflow needed to meet M&I and agricultural water quality standards at various locations in the Delta. Includes carriage water if required (see below)	Determined through G-Model relationships (Denton 1993). Outflow required for each location was determined separately, with the largest used as the requirement for that day.
Carriage water	Outflow required greater than that needed for M&I and agricultural water quality standards, caused by large south Delta export diversions when outflow is low. This was included in either M&I or agricultural Delta water quality (whichever requires more outflow at Jersey Point) unless the Delta Cross-Channel is closed for ecosystem purposes, in which case all or a portion is assigned to ecosystem water quality.	Denton (2006).[(f)] See text for calculation method.
III. Ecosystem water	Water needed to meet outflow or salinity regulations for ecosystem purposes, or outflow generated by export reductions imposed by regulations to protect aquatic species.	See each subcategory.
Ecosystem flows	Outflow required by regulation for ecosystem purposes.	Outflow value from the regulation.
Ecosystem water quality	Outflow necessary to meet water quality regulations established for ecosystem purposes. Includes carriage water if required (see above).	For X2: Of the three ways to meet the standard, the outflow method was used to determine the water assigned. For other standards: Outflow determined by the G-Model relationships (Denton 1993).
Export pumping limits	Water potentially available to be pumped at Banks and Jones that is precluded by export pumping limits. Potential availability means these flows are within the pumping capacity at these plants, without regard to the projects' capability of delivering this water to customers or storing this water south of the Delta.	Flow that is otherwise available to be pumped but cannot be accessed due to export limits. Export limits can be categorized as related to D1485 or D1641, Central Valley Project Improvement Act (CVPIA), pre-2008 ESA, Vernalis Adaptive Management Program (VAMP), or post-2008 ESA. These were calculated separately in this report's data set, but generally combined in the tables and graphs below.
IV. Uncaptured water	Outflow greater than that required for system water and ecosystem water	Dayflow, CDEC, DICU are used to obtain total outflow; uncaptured volume determined by subtracting the outflows assigned to system and ecosystem water.

NOTES:

[a] CCWD diversions are largely through the Central Valley Project (CVP) but include non-CVP water rights. NBA diversions are from the State Water Project.

[b1] California Department of Water Resources. 1995. "Estimation of Delta Island Diversions and Return Flows. Modeling Support Branch. Division of Planning."

[c] California Department of Water Resources. n.d. California Data Exchange Center.

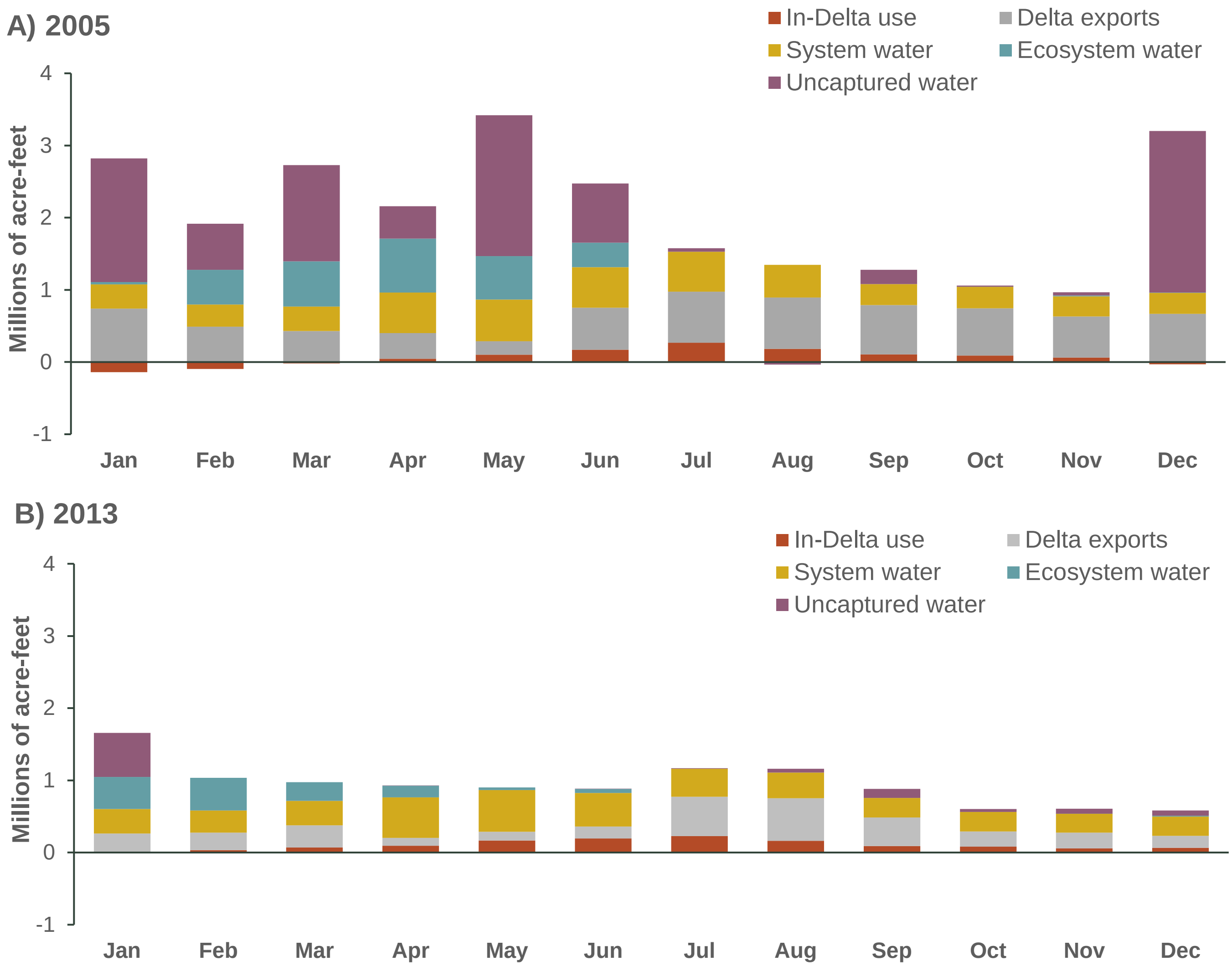
[d] California Department of Water Resources. n.d. Dayflow data.

[e] Denton, R.A. 1993. "Accounting for Antecedent Conditions in Seawater Intrusion Modeling—Applications for the San Francisco Bay-Delta." *Hydraulic Engineering* 93, Vol. 1 pp. 448-453. Proceedings of ASCE National Conference on Hydraulic Engineering, San Francisco.

[f] Denton, R.A. 2006. Presentation to the DSM2 Users Group.

FIGURE B1

Where Delta water went in 2005 (an above-normal year) and 2013 (a dry year)



SOURCE: Detailed source information and methods of calculation are provided in the data set *PPIC Delta Water Accounting*.

NOTES: For a description of the categories shown here, see Table B1. When in-Delta use 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 lower outflow) for a period while the salinity levels rise in the Delta.

In-Delta Use

Before construction of the CVP and SWP, most of the water diverted from the Delta was used by farmers, municipalities, and businesses located in the Delta or along the Carquinez Strait. Historically, the top priority for water that flows into the Delta has been for Delta farms and cities. The "in-Delta use" category also includes water diverted at the Contra Costa Canal and the North Bay Aqueduct (operated by the CVP and SWP, respectively), because they supply local users within the Delta watershed or its immediate vicinity. Historically, these diversions have been small relative to other water uses in the Delta.[27]

In-Delta use includes evaporation from water surfaces and from wetlands. It also includes precipitation that falls within the Delta, which is subtracted from the estimates of the consumptive use by Delta farms and municipalities. When precipitation exceeds consumptive use, in-Delta use can occasionally be negative, as seen in Figure B1a (January through March, and again in December) and Figure B1b (January). As expected for irrigation, in-Delta use is highest in the summer months.

Delta Exports

The CVP and SWP export large amounts of water from the Delta (ranging from 1.5 maf to 6.7 maf annually in the 37-year period examined here).[28] These projects are generally responsible for meeting both system and ecosystem requirements in the Delta. During dry years and dry seasons, Delta pumping, along with water inflows from upstream reservoirs to meet these standards, has a major influence on the hydrodynamics and water quality of the Delta. In wet periods, runoff from the watersheds make up most of Delta inflows and can result in outflows in excess of the minimum needed to meet the standards (uncaptured water). Export pumping is greatest in winter, summer and fall, with less pumping in spring when various requirements are imposed to protect fish (Figure B1). Since 2008, when additional export pumping limits have been imposed, pumping is often low from January through June.

System Water

To sustain in-Delta uses and exports—regardless of any regulations to protect the Delta ecosystem—Delta water quality must meet specified levels. Of greatest concern are salinity levels, which are costly for M&I water treatment and detrimental to crop production. The State Water Resources Control Board (SWRCB) has established standards to guarantee maximum salinity levels to protect these uses. For the period of analysis here, this includes Decision 1485 (D1485), in force from 1978 to 1994, and Decision 1641 (D1641), in force since 1995 (Technical Appendix A).[29] This system water reflects regulatory standards intended to benefit water quality for three types of users:

- **Export water quality.** Substantial Delta outflow is needed throughout the year to maintain salinities low enough for exports. This is in part due to the location of the pumps in the south Delta, in proximity to poor water quality flowing in from the San Joaquin River. In addition, outflow is needed to repel salinity coming in from Suisun Bay and the Carquinez Strait, caused by tides. At times, it is also needed to offset the effects of pumping that, during dry periods, can result in additional salinity intrusion into the central and south Delta. Much of the inflow that enters the Delta from upstream runoff and reservoirs and eventually makes its way into Suisun Bay is associated with keeping the Delta fresh enough for export users. Historically, the maximum salinity desired for export uses was about 250 mg/l chloride or about 1 mS/cm electrical conductivity at the Jones Pump Plant near Tracy (referred to as the "Tracy standard"). During dry periods, such as the recent drought, the volume of system water assigned to support export water quality exceeds the amount of water exported.
- **Delta M&I water quality.** The Delta contains multiple intake points that divert water for M&I uses in cities throughout the region. Many of these intakes are in locations that are vulnerable to salinity intrusion (Figure B2). They require system water outflows that are usually above those needed to maintain water

[27] Typically, the NBA diverts about 45,000 acre-feet (af) per year and CCWD diverts about 120,000 af per year; net in-Delta consumptive use is about 800,000 af (1,600,000 af of consumptive use minus about 700,000 af that falls as precipitation in the Delta).

[28] For reasons described below, we generally present results here by calendar year rather than water year (October to September). The data set *PPIC Delta Water Accounting* provide the data on a daily, monthly, and annual basis, including both calendar years and water years.

[29] D1641 was formally adopted in 1999, but it contains regulations adopted by the SWRCB in its 1995 Water Quality Control Plan. The projects operated to the same regulations starting in 1995 as part of the Delta Accord (Technical Appendix A).

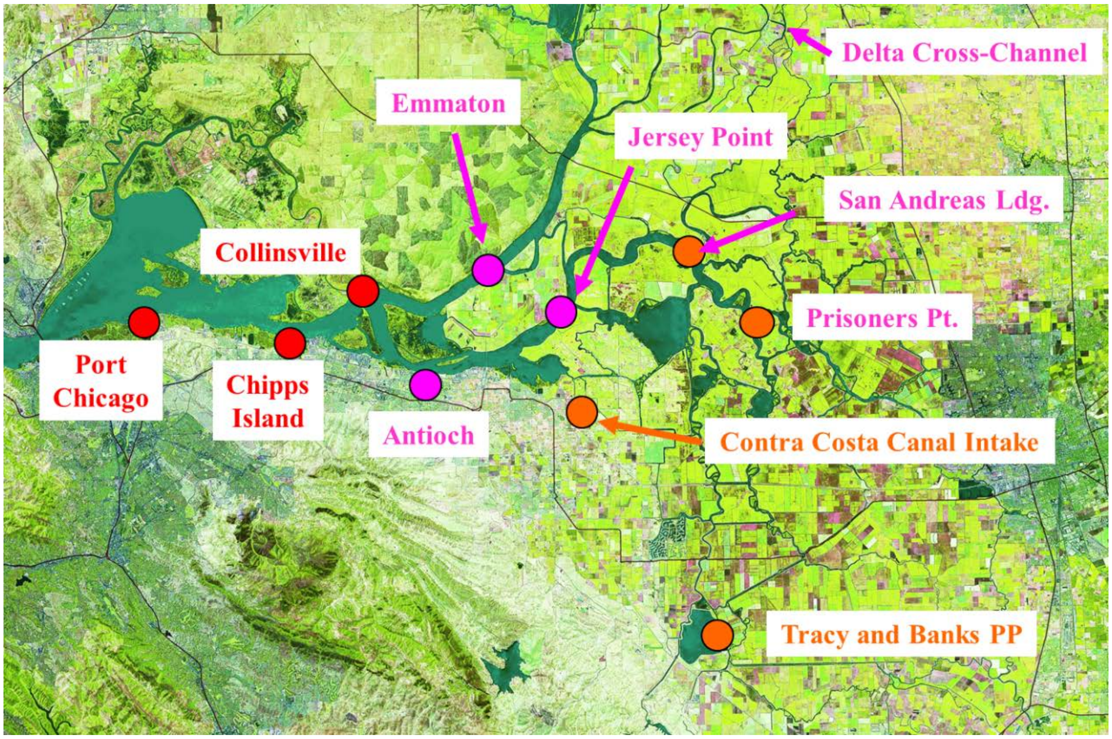
quality for export uses. The SWRCB protects Delta M&I water quality through salinity standards that are defined and monitored at several locations, including the Contra Costa Canal, the North Bay Aqueduct, and the Banks and Jones pumping plants. However, because salinity arrives principally from the west and does not intrude near the NBA, if the standard is met at the Contra Costa Canal it is met at the other locations.[30] When natural runoff is insufficient, the CVP and SWP must comply with these standards by releasing water from their upstream reservoirs or by reducing export pumping. The locations and levels of salinity standards vary by month and water-year type, but some level is required throughout the year. During some periods of high export pumping and low outflow, the amount of outflow required to meet the standards may exceed the levels needed when export pumping is lower. This "carriage water" is included in the accounting.

- **Delta agricultural water quality.** The SWRCB also sets salinity standards in the Delta to protect in-Delta agricultural diversions from April 1 through August 15. In most years it takes additional system water outflow—on top of outflows to meet export and Delta M&I standards—to maintain salinities low enough for agricultural diversions in the western Delta. As with Delta M&I water quality, the CVP and SWP are responsible for meeting these standards through releases from upstream reservoirs or reduced export pumping. Figure B1a shows the largest amount of system water from April to August, when the agricultural standard requires the freshest water (0.45 mS/cm at Jersey Point); Figure B1b shows how system water is reduced in June in dry years, when a higher salinity is allowed (1.35 mS/cm at Jersey Point starting June 15).

System water outflow to provide adequate water quality for exports and in-Delta M&I uses are required all year, while outflow to provide adequate water quality for in-Delta agriculture is required from April to mid-August. Consequently, the requirements overlap and each provides benefits to the others, as well as to the Delta ecosystem.

FIGURE B2

Locations of key water quality regulations under Decision 1485 and Decision 1641



[30] In practice, SWP and CVP operators closely follow the salinity at Jersey Point, the location of one of the agricultural standards, to meet the salinity requirements at the Contra Costa Canal, since the salinity at the Contra Costa Canal is related to the salinity at Jersey Point, with a lag of a week to 10 days.

Ecosystem Water

It is complicated to estimate the volume of water assigned to support the Delta ecosystem. This is due in part to significant changes since the late 1970s in the laws and regulations that protect fish and other instream beneficialuses. But it is mostly because regulators use a mix of direct and indirect ways to manage flows and water quality. Moreover, multiple state and federal agencies set, monitor, and enforce these requirements, and not always in unison. For the period under analysis here, ecosystem water has been required by regulations under D1485 (1978–94), D1641 (since 1995), federal Biological Opinions (BiOps) that implement the ESA (since 1993, with major revisions in 1995 and 2008), the Vernalis Adaptive Management Program (VAMP, since 2000), and the Central Valley Project Improvement Act (CVPIA, since 1992) (Technical Appendix A).

There are three general classes of ecosystem water, with significant overlap. All of them overlap with and are bolstered by system water requirements.

- **Ecosystem flows.** Depending on the season and water-year type, regulators will stipulate that a certain volume of water must flow into the Delta from the San Joaquin River and its tributaries, or they will define how much water must flow out of the Delta into Suisun Bay. On any given day, multiple regulations can establish these inflow and outflow requirements. We calculated all of them and used the flow standard that resulted in the highest total required for that day (on the assumption that the others are met if the highest is met). Ecosystem flows were required under D1485 and were entirely revised under D1641 in 1995. Additional ecosystem flows were required under the CVPIA, VAMP, and ESA.
- **Ecosystem water quality.** State and federal regulators have set multiple salinity standards throughout the Delta to improve conditions for native fish. We have estimated the volume of Delta outflow needed to meet these standards, which are often higher than those set for agriculture and M&I uses. As with ecosystem flow requirements, ecosystem water quality requirements often overlap, as the satisfaction of one standard at one location can also satisfy different standards at multiple locations.[31] Ecosystem water quality requirements to enhance conditions for striped bass (including food for striped bass) were promulgated in 1978 under D1485. Almost all of those standards were replaced in D1641 with the X2 salinity standard and ecosystem flows discussed above. ESA BiOp requirements added fall X2 in 2008.
- **Export pumping limits.** The CVP and SWP pumps have direct and indirect impacts on native fishes. To reduce these impacts, regulators limit the timing and volume of pumping. This can have the net effect of increasing Delta outflows by reducing the amount diverted for exports.[32] Controls on pumping include setting limits on the volume of exports during a certain period, limiting pumping based on the amount of inflow, controlling pumping to reduce reverse flows in Delta channels, and restricting pumping to reduce entrainment of fish. D1485 had export pumping limits from May through July to protect striped bass. These were replaced in 1995 (in the Delta Accord and D1641) with pumping limits throughout the year (based on a percentage of Delta inflow) and pumping limits during the spring pulse flow period. The ESA, CVPIA, and VAMP—implemented after 1995—combined to add export pumping limits during the pulse flow period. In 2008, a revision of the ESA Biological Opinions led to additional pumping limits (through limits on the net flow in Old and Middle Rivers). While we measure the effects of water quality and outflow requirements from the "bottom up" (i.e., from zero outflow up to the required daily level), we measure the effect of export limits from the "top down." That is, the ecosystem is assigned the amount of water that would have been available for pumping, up to the limit of the pumping capacity.

In our building block accounting approach, ecosystem water is the additional outflow required to protect fish and other instream beneficial uses, above and beyond the flows required to protect water quality for Delta diversions

[31] For example, the X2 requirement in February requires 2 ppt (about 3.2 mS/cm) at Collinsville. The Suisun Marsh standards require 8 mS/cm at the same time. If the X2 standard is met (which requires about 7,100 cfs outflow) the Suisun Marsh standard at Collinsville is also met, as is the 150 mg/l M&I standard which requires about 5,500 cfs at the same time. As long as the X2 standard is met, so are the overlapping requirements.

[32] In some cases, especially in dry periods, project operators can reduce releases from reservoirs when they are required to reduce exports and there will be no additional outflow; in these situations, the limits have no immediate effect on outflow and the exports may be deferred until later in the year.

(system water). There is significant overlap between system water requirements and both ecosystem flow and quality requirements. In contrast, export pumping limits do not have overlapping requirements with system water, so they are always counted as additional outflow for ecosystem purposes.

Ecosystem flow and water quality requirements increase with the amount of annual runoff. Although they always overlap with system water requirements, they are not always larger. System water outflow is slightly larger in late summer and fall; hence, ecosystem water is small or zero in those months (Figure B1). Ecosystem water is greatest in the winter and spring: this is when X2 water quality requirements and export pumping limits are the largest.

Uncaptured Water

Inflows to the Delta often exceed both the required system and ecosystem water outflows and the capacity of in-Delta users and export facilities to divert water. This is most common during winter high flow pulses or periods of high snowmelt runoff when upstream reservoirs are close to capacity and are spilling water. This uncaptured water helps meet salinity regulations by freshening the Delta so that later, when inflows subside, the low salinity levels can remain for an extended period.[33] However, we did not use these antecedent conditions to estimate the day-to-day amount of system and ecosystem water needed.[34] Instead we used a steady-state approach that allows a good estimate of the outflow required as long as it is used on an average basis (averaging over months or years).

Figure B1 offers an example of how uncaptured water is assigned—and the inherent complexities in those assignments. Figure B1a shows the monthly accounting for 2005, an above-normal year. There are large uncaptured flows from January through June. Because of the large winter and spring runoff, the projects were not releasing extra water from reservoirs to meet assigned outflow requirements in those months. However, they were required to cut back on diversions during the spring to protect fish, which adds to the water assigned to the ecosystem and reduces the amount assigned to uncaptured water.

In Figure B1 (panel B), which shows monthly flows for the dry year 2013, there appears to be a small amount of uncaptured water from September through November (on the order of 1,000 cfs or 0.06 maf/month). This demonstrates some of the uncertainty in calculating outflow: we have used DWR’s DICU values (see Table B1) instead of the “standard” Dayflow values. The difference between these sources can be on the order of 1,000 cfs or more in some months. Thus, what is shown as uncaptured water in these months could be the result of the uncertainty in the estimation of either in-Delta use or the outflow required (which also depends on in-Delta use estimates). Since we estimate uncaptured water by difference, after accounting for all other components of Delta inflows, any errors will accumulate into this category. Readers are therefore advised against over interpreting the data, especially on a monthly or daily basis.

Figure B1a also shows a period (August) when uncaptured outflow was negative. This often occurs in August, reflecting the end of higher Delta agricultural water quality standards on August 15. The Delta M&I standard controls thereafter, and it requires a much lower outflow. CVP and SWP project operators take advantage of the transition from higher to lower salinity standards by reducing outflow well below the amount normally necessary as the standard changes. By speeding up the salinity intrusion that might otherwise take several weeks, they are able to harvest outflow (by increasing export pumping, releasing less water from reservoirs, or some combination of these two strategies). The result in the accounting is a period when outflow is less than that normally required during the transition between different standards, which shows up as “negative” uncaptured flow.

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[33] When there are uncaptured flows, salinity in the Delta will generally fall below the maximum levels required by regulations; when flows are reduced later in the season, the Delta slowly responds because salinity intrusion, driven by tidal flows, is a relatively slow process. Thus, the effect of high flows can linger for weeks and months, allowing higher diversions (and lower outflows) than would otherwise be necessary.

[34] The reason for this is that there is no unique answer to determining the flow needed to meet a salinity level on any day when antecedent conditions are taken into account.

Caveats and Limitations of this Analysis

It is important that readers recognize several caveats and limitations of this analysis to avoid misinterpreting the results.

Assigned Regulatory Outflows versus Cost to Water Exports

Because the CVP and SWP are responsible for meeting the various water quality and flow requirements in the Delta, these regulations can affect the volumes of water available for export from the south Delta pumps. However, our estimates of system and ecosystem water required by regulations do not measure the impact of regulations on export volumes. Rather, our estimates provide an upper bound on this impact. In some cases, especially under dry conditions, our estimates may be quite similar to actual reductions in export quantities. In most cases, however, the actual cost of regulations in terms of reduced exports is well below assigned system and ecosystem water. This is the result of several factors:

- **Salinity.** Salinity limits in the Delta are critical for meeting both system and ecosystem water quality requirements. Yet, salinity levels are not simply a function of outflow or volume of diversions at a given time. They depend on the magnitude of outflows over the previous few months, along with other factors such as tides and winds. For example, in 2011 exceptionally high volumes of uncaptured outflow kept the Delta unusually fresh, with low salinities all the way to San Pablo Bay well into summer. Under these conditions, little to no upstream releases or pumping reductions were needed to meet salinity standards. This phenomenon even occurs in drier years, when winter flow pulses freshen the Delta. When such pulses occur, less inflow is needed to meet salinity standards for an extended period. Under such conditions, the actual cost of regulations to export water deliveries can be zero, since the salinity requirements are met by high runoff. In other words, there is enough water available to meet system and ecosystem water quality requirements without affecting export water availability.
- **Flow standards.** The same caveat applies to ecosystem flow standards. During high runoff events, nature provides the flows needed to meet many of these standards, particularly during the winter and spring.
- **Export pumping limits.** In contrast to salinity and flow standards, export pumping limits often represent a direct cost to export capacity when they are being enforced. However, it is sometimes possible for the CVP and SWP to make up the losses—particularly in wetter years—by holding water in storage until later in the year and pumping when restrictions are relaxed.[35]

Thus, it would be incorrect to cite system and ecosystem water volumes shown here as a necessary cost to project operations. In general, our estimates will be greater than the loss of deliveries to the projects, although in some cases—typically during dry years or dry months of any year—they can be nearly the same. Below, we compare our results with the findings of a study that looked at the effects of changing ecosystem regulations since the mid-1990s on Delta exports (MBK Engineers and HDR 2013).

Water Years versus Calendar Years

We have chosen to base the calculations on calendar years rather than the water year (October 1 to September 30 of the following year). Although many regulations are based on water year classifications, their application is tied more closely to the calendar year.[36] For example, since the 1994 Bay-Delta Accord, regulations that depend on

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[35] This was quite common from 1995 to the mid-2000s and a feature of the 1994 Bay-Delta Accord, which allowed for pumping limits (to reduce take of fish) to be made up later. Under the 1995 Biological Opinions, regulatory agencies could propose, and the projects could accept, pumping limits if the pumping could be made up later. From 1995 to 2000, this was often done; export losses were almost always easily recovered because it was a very wet period. After 2000, the Environmental Water Account provided another means to ensure the water lost was made up. In very dry periods like 2014 and 2015, low availability of water from runoff and upstream reservoirs is the principal limit on exports, so export pumping limits have a much smaller additional impact, and sometimes none at all.

[36] Many salinity and flow regulations are based upon the hydrologic classification of the year. The year type is based upon runoff estimates from October 1 to September 30, but the classification for October through January is based on the prior water year; the first change comes officially with the February forecast as

monthly hydrologic conditions start in January (e.g., minimum outflow is determined by December runoff). Using calendar years instead of water years gives a simpler representation of how flow and water quality standards are applied. Most of the results presented here are on a calendar year basis. 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* also provide the data in multiple time steps (daily, monthly, calendar year, and water year) to facilitate comparisons.

Converting Salinity Standards to Assigned Water

As noted above, salinity conditions in the Delta are a function of many factors, including inflow, pumping, outflow, winds, and tidal conditions over time (Monismith 2016). Many combinations of these factors can lead to the same salinity conditions, leaving no unique answer. The fact that salinity depends upon the history of outflow, not just the current outflow, makes it difficult to assign a unique outflow for a given level of salinity without making some simplifying assumptions that allow good approximations.

In addition, salinity levels in the Delta can be affected by the opening and closing of the Delta Cross-Channel (DCC) on the Sacramento River. Opening the DCC directs high quality Sacramento River water into the interior channels of the Delta and improves water quality near the south Delta export pumps. This lessens the need for increased outflows to meet system water requirements. However, regulations to protect fish require that the gates be closed periodically.

We have addressed this complexity by using a salinity model that predicts salinity given the history of outflows over time (Denton 1993). Denton's "G-model" uses the history of Delta outflows to estimate an equivalent steady-state outflow for a given salinity level (that is, the constant outflow that would be needed to produce a salinity level). We use this to calculate the outflow necessary to meet system and ecosystem salinity standards.[37]

Denton's methodology also provides a means for calculating "carriage water" when that is needed (essentially during low outflow, high pumping conditions), including whether the DCC is open or closed.[38] In general, carriage water is a small fraction of the outflow needed to meet required salinity conditions (averaging about 0.1 maf per year, though much higher in some years, compared to a total of about 3–5 maf annually needed to meet D1485 and D1641 water quality standards).[39]

When the DCC is closed for ecosystem purposes, the increment of carriage water caused by the closure is accounted for as part of water assigned to the ecosystem; when the closure is due entirely to CVP and SWP

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published by DWR in Bulletin 120. Under Decision 1641, January outflow is determined by December runoff estimates; February through June X2 requirements are changed each month depending on the prior month's runoff. Thus, accounting for assigned water is easier within a calendar year.

[37] *PPIC Delta Water Accounting* contains a more detailed description of the method.

[38] Increasing south Delta pumping may require an increase in inflow, all else being equal, to keep constant salinity in the south Delta. Generally, that increase is accomplished by increasing Sacramento River inflow, which will both increase the net flow up the lower San Joaquin River toward the export pumps, as well as through the interior of the Delta (Georgiana Slough and the Delta Cross-Channel, if it is open). The increased flow from the Sacramento River will freshen water moving through Threemile Slough, Georgiana Slough and the DCC to the lower San Joaquin River. Combined with increased flows down Middle River, that will reduce salinity at first. As exports and inflows further increase, the salinity can start to increase, requiring greater outflow to offset the increase in salinity. The G-model formulation (for steady-state) is $CW = Qo\ ((1+\gamma\ Qwest)\text{-}1 - 1)$, where CW is the carriage water (additional outflow needed to maintain salinity), Qo is the steady-state outflow for a given salinity at Jersey Point, γ is a calibration constant in the model, and Qwest is the net reverse flow in the lower San Joaquin River. We used this method because it is a functional relationship, easily implemented. In wetter periods, when outflow is above about 10,000 cfs, carriage water is not necessary as the salinity in the lower San Joaquin River is so low that increased pumping levels have no effect. In very dry periods, pumping levels are often very low; when pumping is low, carriage water is not required. These factors lead to a relatively small effect on average, although carriage water can be significant at times.

[39] We calculate carriage water as the portion of outflow needed because of high south Delta pumping levels when outflow is relatively low. We do not include "negative" carriage water, which occurs in some situations at low pumping levels that tend to freshen the south Delta as pumping increases (this has generally small effects). For a good discussion of carriage water, see Chapter 8 "An Initial Assessment of Delta Carriage Water Requirements Using a New CALSIM Flow-Salinity Routine," in California Department of Water Resources (2001).

operations (such as flood control or to meet the agricultural water quality standard at Emmaton[40]), it is accounted for as part of system requirements for water quality (in-Delta M&I or agriculture).

Because multiple factors that interact over time control salinity in the Delta, calculations for a given day are likely to exhibit considerable uncertainty and should not be used for precise evaluation. However, these complexities average out over time to give a reasonable estimate of outflow/salinity relationships over the course of months.

An additional complexity comes from an apparent increase in outflow required to meet a given salinity level over the period under review. Based upon the calibration of salinity models to field data, it appears that somewhat less outflow was required prior to the mid- to late-1990s than more recently.

Several factors have been proposed anecdotally that might have caused this shift, including the operation of the Montezuma Slough Salinity Control Gates and channel dredging, as well as possible changes in Delta consumptive use (which affects the estimates of outflow used in the calibration).[41] It is also possible that the longer record now available covers more extreme conditions, allowing better calibration of models. Pre-1995 and post-1995 calibration of the G-model (incorporating the carriage water formulation) suggests that about 500 to 800 cfs more outflow is needed now than in prior times for the same salinity levels—or about 400,000–600,000 acre-feet (af) per year. We have incorporated this increase into our estimates. This can be seen in Table B2, which summarizes the important regulatory parameters that can determine the required outflow on any day, and the estimated steady-state outflow associated with the parameters.

TABLE B2

Outflow required for water quality and outflow regulations, 1980–2016

Location	Outflow or salinity standard		Outflow required (cfs) [a]
Tracy, Banks	Baseline Tracy Standard, D1485 and D1641 250 mg/l, 1 mS/cm[b]		3200 pre-1995[c] 3700 post-1995
Contra Costa Canal Intake	D1485 and D1641[d]	250 mg/l Cl	3800 pre-1995 4400 post-1995
		150 mg/l Cl	4700 pre-1995 5500 post-1995
Emmaton	D1485 and D1641[e]	0.45 mS/cm	8200 pre-1995 9400 post-1995
		0.63	7300 pre-1995 8400 post-1995
		1.14	5900 pre-1995 7000 post-1995
		1.67	5100 pre-1995 6200 post-1995
		2.78	4200 pre-1995 5200 post-1995 4100 TUCP[f]
Jersey Point	D1485 and D1641[g]	0.45 mS/cm	7300 pre-1995 8500 post-1995
		0.74	6000 pre-1995 7000 post-1995
		1.35	4700 pre-1995 5500 post-1995
		2.2	3800 pre-1995 4500 post-1995

[40] The water quality at Emmaton is affected by closures of the DCC, which diverts water out of the Sacramento River, leaving less to flow by Emmaton. At times when outflow is low, project operators will close the DCC to freshen the water at Emmaton to meet the standard (but of course, that has an adverse effect on salinity at Jersey Point, which also has a water quality standard to be met).

[41] Sea level rise is another possible factor, and is likely to become important in the future. Models show that sea level rise will likely increase salinity levels, requiring greater outflows to meet water quality objectives (Fleenor et al. 2008, MacWilliams et al. 2016). The magnitude of salinity increases depend upon the amount of sea level rise and the configuration of the Delta shoreline and channels. Changes in Delta islands—particularly flooding of Delta islands and restoring tidal marshes—impact tidal energy, which controls salinity intrusion.

San Andreas Landing	D1485 and D1641[h]	0.45 mS/cm 0.58 0.87	4700 pre-1995 5400 post-1995 4200 pre-1995 4900 post-1995 3400 pre-1995 4000 post-1995
Prisoners Point	D1485[h] D1641[h]	0.55 mS/cm 0.44 mS/cm	4300 pre-1995 5500 post-1995
Antioch	D1485[i]	1.5 mS/cm 2.5 4.4 10.3 25.2	7400 pre-1995 6000 pre-1995 4500 pre-1995 2400 pre-1995 170 pre-1995
Collinsville X2	D1641[j]		7100
Chipps Island X2	D1641[j]		11400
Port Chicago X2	D1641[j]		29200

NOTES: For locations referenced here, see Figure B2; for a description of the regulations see Technical Appendix A.
a: All values are rounded.
b: G-Model at Jersey Point with relationship Banks:Jersey Point ratio.
c: See text; salinity-outflow relationships appear to have changed over time.
d: G-Model at Jersey Point, with relationship CCCI:Jersey Point ratio, plus carriage water.
e: G-Model at Emmaton.
f: Location moved to Threemile Slough in 2014 and 2015 under TUCP.
g: G-Model at Jersey Point, with carriage water.
h: G-Model at Jersey Point, with relationship SAL:Jersey Point ratio or PP:Jersey Point ratio.
i: G-Model at Antioch.
j: Level set by D1641 (one of the three ways to meet the standard).

Calculating Uncaptured Water

To estimate the monthly or annual levels of system and ecosystem water, we applied the applicable values in Table B2 for each day for each salinity standard. Carriage water was included where appropriate, and the largest outflow from those calculations was used as the required level for that day. The amounts needed for the Tracy standard, the Delta M&I water quality standard, Delta agricultural standards, ecosystem flows and salinity standards and pumping limitations were tabulated separately so that they could be compared. Delta inflows and diversions were included from Dayflow and CDEC, and uncaptured flows were determined as the residual (Delta inflows minus water diversions, system water, and ecosystem water).[42]

Because uncaptured water is calculated as a residual, any errors in estimating required system or ecosystem outflow, in-Delta consumptive use, or measured flows will accumulate into uncaptured water in our accounting. We have used DWR's DICU estimates for consumptive use in the Delta; these differ from the "standard" consumptive use numbers shown in Dayflow and those used for the daily operations of the projects. The G-model was initially calibrated using DWR's then-best estimates of consumptive use, and has gone through a number of more recent calibrations using those and other estimates. The DICU estimates are on average about 0.1 maf/year lower than the Dayflow values but can be as much as 0.4 maf/year lower (largely in dry years). Consumptive use estimates are key to determining Delta outflow and in calibrating salinity models accurately, so this gives an idea of the range of the error that can accumulate in uncaptured water from all these factors. Obviously, in wet periods, uncaptured water is very large and consumptive use can be negligible. But in dry periods, the opposite is true, requiring caution in the use of uncaptured outflow estimates on a short time scale, such as daily or monthly intervals.

Other Assigned Water: Upstream Storage and Flow Regulations

In this report we have taken a Delta-centric approach and focused on accounting for environmental water as a share of water flowing into the Delta. This approach does not account for other ways of assigning environmental water, such as instream flow requirements upstream of the Delta and dedication of a portion of reservoir storage

[42] Details on the calculations and data used can be found in the data set *PPIC Delta Water Accounting*.

for ecosystem needs. Although this water may be required to provide ecological benefits upstream of the Delta, the same flows may also contribute to Delta inflow. Once in the Delta, the water may contribute to in-Delta use or exports, system or ecosystem water, or uncaptured outflow.

Accounting for the contributions of upstream water can be challenging, given the way the water system is operated. For example, to account for 800,000 af of water required for ecosystem support annually under the Central Valley Project Improvement Act (CVPIA), the US Bureau of Reclamation (USBR) measures the water assigned to actions upstream of the Delta as the difference between reservoir releases for a flow action and the releases that would have been made in a baseline that does not include those actions. For the most part, this is an adequate measure, but it can lead to complications once the water gets to the Delta.

Delta inflows are not accounted for by source. Upstream river flows are generally available for diversion by senior water-right holders. Once flows reach the Delta, they are essentially under the control of the regulatory agencies (in terms of required outflows or export pumping limits) and the SWP and CVP (in terms of pumping as much as they can, provided that the water flow and quality requirements and pumping limits are met).

In some cases, a reservoir release to support upstream ecosystem requirements can increase Delta outflow. For example, releases to meet San Joaquin River inflow requirements may arrive at a time when export pumping is constrained and cannot be increased, and Sacramento River inflows cannot be reduced. But at other times, the increase in flow from one reservoir can be balanced by reduced flows from another reservoir, with little or no change to Delta inflows. For example, increased summer releases from Shasta Reservoir to meet temperature requirements commonly result in reduced releases from Oroville or Folsom Reservoirs. This can allow the projects to meet Delta outflow requirements without releasing additional water or changing total export rates.

Another upstream action involving ecosystem water is the reservation of stored water, such as a requirement to have a minimum level of storage in a reservoir at the end of a month or a season. An example is the requirement to target storage in Shasta Reservoir at 1.9 maf at the end of September to have sufficient water available for salmon the following year. This can have a marked impact on the ability of the CVP to deliver water, since it puts this water off limits for release for project purposes (whether directly for delivery or for meeting Delta outflow requirements).

In all cases, upstream actions that allocate water for river flows or reserve it in storage can be independent of Delta actions; that is, the water released for instream flow purposes may or may not be also used for Delta purposes (required outflow or diversions). Accounting for these actions in an integrated fashion is complex and can require modeling (to get a baseline without the regulations, and then the effects with the action). And even then, the result will be an estimate that depends on assumptions used in the model.

USBR had to confront this difficulty directly in accounting for the 800,000 af of yearly ecosystem water required under CVPIA §3406 (b)(2). It resolved the issue by accounting for the upstream actions and Delta actions separately and adding them together. Because of the complexity of doing it otherwise, there is great deal of merit in this simplified approach.[43] One limitation, however, is that in practice, the upstream and downstream ecosystem water volumes are not necessarily additive—if the water can be repurposed once it reaches the Delta.

Results: Assigned Regulatory Flows from 1980–2016

In this section, we review the apportionment of Delta inflows between water diversions (in-Delta and exports), water assigned by regulations for system water quality and ecosystem protection, and uncaptured outflows. We

[43] Note that USBR does not include reserved storage in that accounting, since its accounting defines an action under the CVPIA Section 3406 (b)(2) to be a release from storage (above a baseline) or a change in pumping to carry out an action.

first examine the period 1980–94, when the primary regulations for Delta flows were included in the SWRCB's D1485 water quality control plan. We then examine the period 1995–2016, which operated under D1641 and multiple other environmental laws that governed ecosystem flows.

1980–1994: Assigned Water under D1485 and Other Regulations

During the period 1980–1994, the SWRCB's D1485 regulations were the primary determinant of regulatory flows in the Delta. In addition, ESA export pumping limits were imposed in 1993 and 1994 (to reduce take of winter-run Chinook salmon). Figure B3 summarizes the apportionment of Delta inflows annually for this period. Panel A accounts for all the inflow—collapsing the different categories of system and ecosystem water into two summary categories—and shows uncaptured flows, which are quite large in some years. Panel B provides a detailed breakdown of water assigned for different categories of system water and ecosystem water, but omits uncaptured outflow so details can be seen. Each year shows the hydrologic year classification used for regulatory purposes.

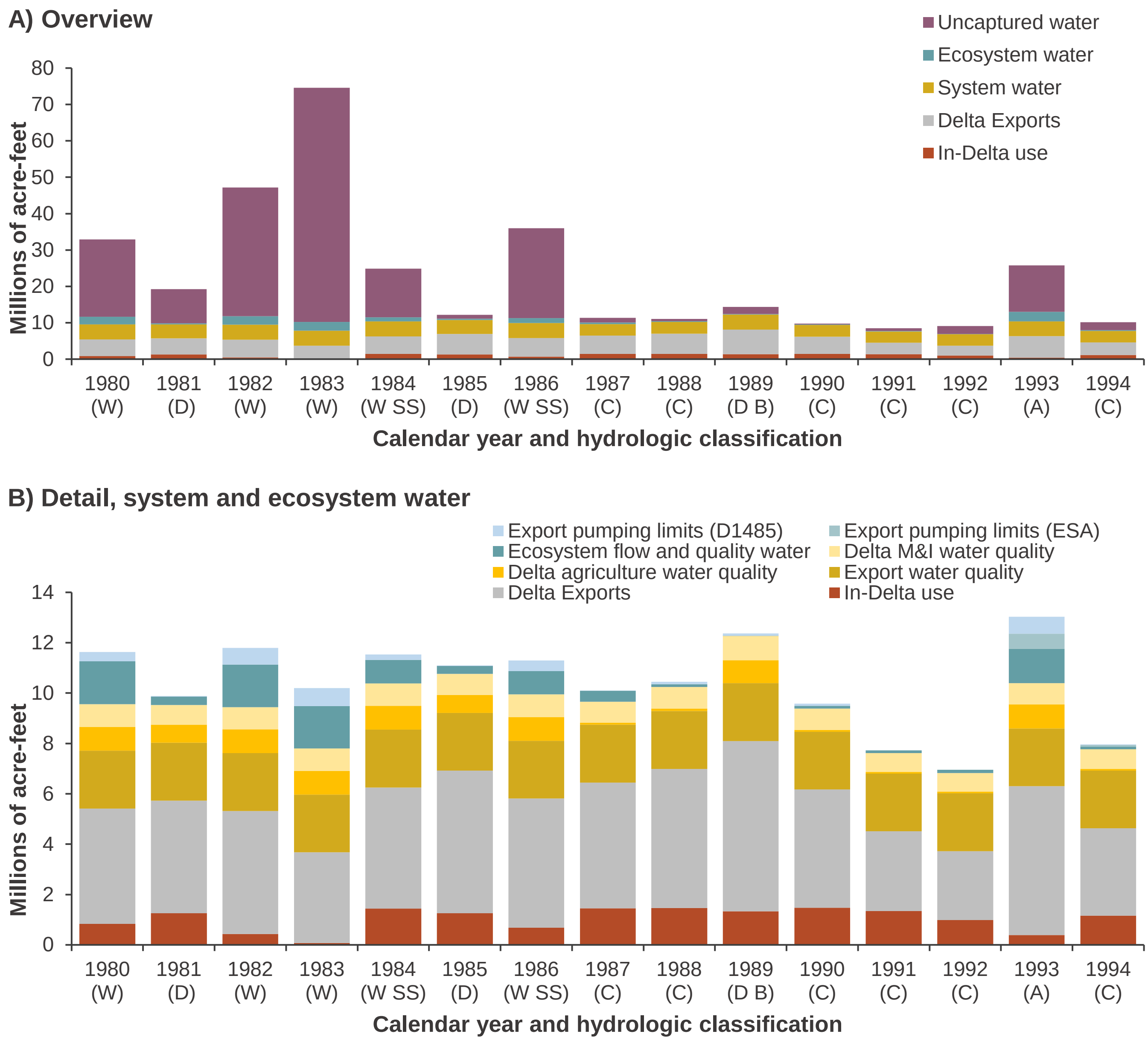
The volumes of assigned water varied greatly during this period, driven by variations in the volume of inflow and associated changes in both water demand for in-Delta and export uses and regulatory requirements.

- Assigned system water outflow required a minimum of 3.2 maf during critically dry years and averaged approximately 4.1 maf in below normal, above normal and wet years.
- Under D1485 there were few protections for the ecosystem in dry years beyond that provided by system outflow for diversion water quality, particularly during the 1987–92 drought. Assigned ecosystem water during this drought was approximately 150,000 af per year—less than 5 percent of the amount exported and 2 percent of total inflow.
- In dry years, very little water was assigned to ecosystem water through export pumping limits, which were in effect from May to July under D1485. Pumping levels were often below the limits because there was insufficient inflow due to drought.
- In wet years, ecosystem water averaged approximately 1.9 maf—39 percent of the volume exported and 4 percent of total Delta inflow. Often, however, meeting the ecosystem outflow requirements did not require export reductions or additional reservoir releases, as runoff provided ample flow.[44]
- During the extreme wet year of 1983, exports dropped to 3.7 maf, almost half of the peak level of exports during this period (6.9 maf in 1989, during the multi-year drought).[45] Annual in-Delta use was near zero because precipitation in the Delta offset consumptive use.
- The following rules of thumb apply to assigned water in this period:
  - **In dry and critically dry years**, for every acre-foot of water diverted for use in-Delta or as exports approximately 0.6 acre-foot of system water outflow was needed to maintain water quality for that use. An additional 0.05 acre-foot of ecosystem water was needed to meet regulations for the health of the Delta. In total, 0.65 of outflow was needed for every acre-foot diverted from the Delta.
  - **In wet years**, for every acre-foot of water used approximately 0.8 acre-foot of system water outflow was needed to maintain water quality for that use. An additional 0.35 acre-foot of ecosystem water was needed to meet regulations for the health of the Delta ecosystem. In total, 1.15 acre-feet of outflow was required for every acre-foot diverted from the Delta.

[44] This is demonstrated by the fact that the export levels were often below the allowable levels in these periods, while at other times there was no uncaptured flow.
[45] Up until the early 1990s, when additional pumps were added at the SWP's Banks Pumping Plant, exports were also limited by a lower pumping capacity (6,400 cfs).

FIGURE B3

Where Delta water went, 1980–1994



SOURCE: See Table B1.

NOTES: Hydrologic classifications are based on D1485. W=wet, A=above normal, B=below normal, D=dry, C=critically dry. SS indicates a year with subnormal snowmelt, when D1485 allowed relaxations. The year 1989 followed a critically dry year, and therefore had a dry classification for ecosystem flows, and below normal for system flows.

1995–2016: Assigned Water under D1641 and Other Regulations

From 1995 onward, D1641 replaced D1485 as the set of system and ecosystem water regulations administered by the SWRCB.[46] System water regulations to protect diversion water quality remained unchanged. But there were several changes to ecosystem water requirements. The striped bass protections of D1485 were removed, and the current ecosystem outflow and water quality regulations were included. This included the X2 salinity

[46] The Delta Accord was implemented under the BiOps from 1995 until D1641 was adopted in 1999; it applied the standards put in place under the accord (Technical Appendix A).

requirement, which requires minimum outflow or equivalent water quality levels from February through June and minimum outflows in each of the other months (July through January) for fish protection. Export pumping limits were included for every month.

This period also saw increasing influence of several other regulatory programs affecting ecosystem water. The ESA BiOps, CVPIA, and VAMP were used to increase the export limits during the spring pulse flow period. In 2008, the revised BiOps included new export restrictions from mid-December through June, at times greatly limiting exports, especially in wet periods.

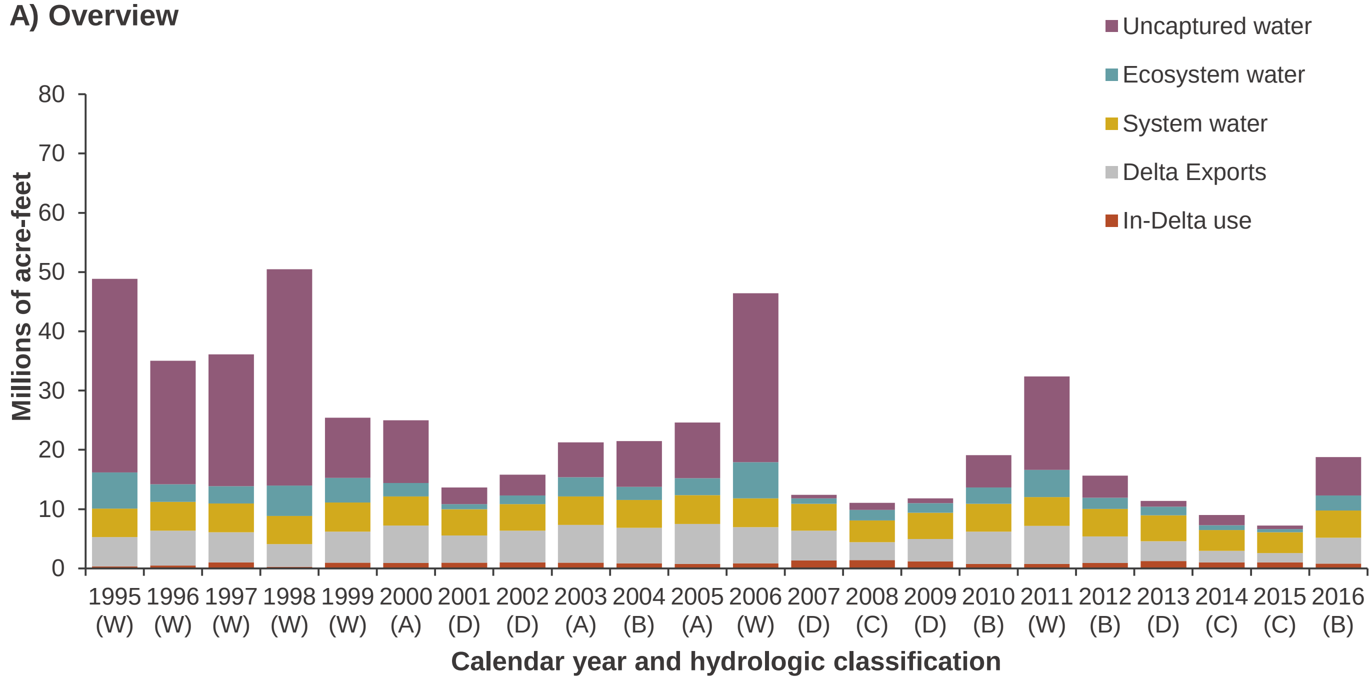
Figure B4 summarizes the apportionment of Delta inflows for this period. As above, Panel A shows system and ecosystem totals, but includes uncaptured outflows, while Panel B provides a more detailed breakdown of water assigned for system and ecosystem water.

Table B3 reports the average volumes of water for in-Delta use and exports, along with our estimates of system and ecosystem water, for the entire 1980–2016 period. In this table we have broken down the 37-year span into three sub-periods reflecting different regulatory regimes: the 1980–94 years when D1485 was in effect, the 1995–2007 years under D1641, and the 2008–16 years when D1641 was still in effect but some ESA regulations became stricter (particularly export pumping limits). This table shows values for different water year types, highlighting key differences between wet and dry years.

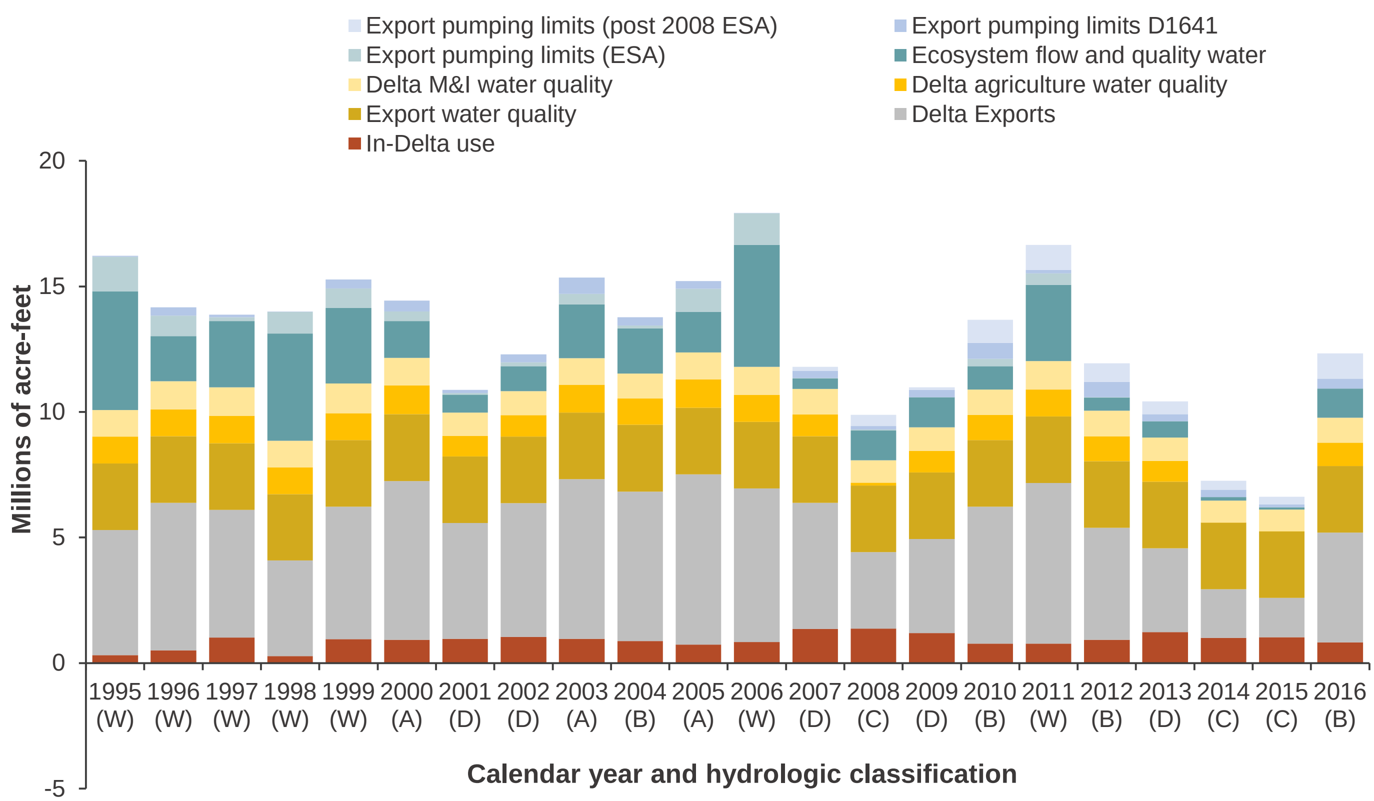
FIGURE B4

Where Delta water went, 1995–2016

A) Overview



B) Details of system and ecosystem water



SOURCE: See Table B1.

NOTE: Hydrologic classifications are based on D1641. W=wet, A=above normal, B=below normal, D=dry, C=critically dry.

TABLE B3
Average annual water use and assigned regulatory flows in three periods (1980–2016)

Period and year type	Number of years	Total inflow (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

NOTES: The data are reported in calendar years. The column for number of years shows years included in the average values shown in each row. Not all hydrologic classifications were represented in each period.

As in 1980–94, the volume of system and ecosystem water during the 1995–2016 period varied widely, depending primarily on the quantity of inflow across several wet periods and two multi-year droughts.

- System water outflows under D1641 ranged from approximately 3.6–4.9 maf per year, an increase of 400,000–600,000 af per year to meet salinity targets similar to those in place under D1485. As described earlier, the causes of this increase are not well understood, but may include changes in in-Delta use (which is estimated), operation of the Montezuma Slough Salinity Control Structure, sea level rise, channel changes, and improved model calibration with a larger field data set.
- The lowest volume of system water (3.5 maf per year) occurred in 2015 at the height of the latest drought, when salinity standards were relaxed under a temporary urgency change petition and salinity barriers were installed to reduce the need for reservoir releases.[47]
- From 1995–2016, total annual ecosystem water varied from 0.1–4.8 maf per year—a significant increase over D1495. During dry and critically dry years, ecosystem water averaged 1.2 maf, versus just 0.3 maf under D1485. In wet years, ecosystem water averaged 4.6 maf, versus 1.9 maf under D1485. However, given the large amount of uncaptured water in these years, the ecosystem water likely had minimal impact on Delta exports.

[47] In that year, the projects estimated that they reduced outflows by more than 900,000 af under the temporary urgency change orders. These relaxations affected both system and ecosystem water.

- D1641 export pumping limits varied from zero to over 0.6 maf per year.[48] In dry and wet years, these limits were lowest (averaging around 0.15–0.25 maf) while above normal years had over 0.4 maf.
- Before the implementation of the 2008 BiOps, CVPIA, VAMP, and ESA pumping limits averaged under 0.03 maf in dry years, and over 0.8 maf in wet years, rising to over 1.2 maf in the wettest years. Post–2008 ESA pumping limits ranged from 0.1–1 maf per year, with the largest amounts coming in wet years. In critically dry years, they averaged about 0.4 maf. CVPIA and VAMP pumping limits sometimes increased this amount, ranging from zero in critically dry years to over 0.45 maf in 2011 (a wet year).
- At the height of the drought (2015), water assigned to the ecosystem hit a low of 500,000 maf. This was one-third of the amount of water exported that year, and 7 percent of total inflow to the Delta. Total system water—required to maintain salinity levels suitable for Delta agriculture—was 3.5 maf, more than twice the quantity of water exported in 2015 (about 1.6 maf). System water needed just to meet the Tracy standard for exports was about 2.6 maf.
- The following rules of thumb apply to assigned water under post-2008 regulations:[49]
    - For every acre-foot of water diverted during dry and critically dry years, about 1 acre-foot of system water is needed to maintain sufficient water quality for in-Delta uses and exports. An additional 0.3 acre-foot is needed to meet ecosystem regulations, for a total of 1.3 acre-feet outflow per acre-foot diverted. This represents an increase of 0.4 acre-foot of system water and 0.3 acre-foot of ecosystem water per acre-foot diverted relative to 1980–94.[50]
    - In wet years, for every acre-foot of water used, approximately 0.8 acre-foot of system water is needed to maintain water quality for that use. An additional 0.7 acre-foot of outflow is needed to meet ecosystem standards, for a total of 1.5 acre-foot per acre-foot diverted. This represents a constant ratio of system water and an increase of 0.35 acre-foot of ecosystem water per acre-foot diverted relative to 1980–94.[51]

Assigned Water Compared with Total Water Available in the Watershed

The amount of water assigned to Delta system and ecosystem requirements can affect water management throughout the Sacramento–San Joaquin River and Delta watershed, especially when water releases from project reservoirs or reductions in pumping are needed to maintain regulatory requirements in the Delta. To assess this, we compare assigned water with the overall water balance of the watershed since 1995.[52]

Using data developed by DWR for unimpaired flow—meaning water that would have been Delta inflow in the absence of reservoirs and diversions upstream—we reconstructed watershed hydrology for the period 1995–2015, including water stored and released from major reservoirs and water imported from outside of the basin.[53] Using annual estimates of unimpaired flows, water imported into the watershed from the Trinity River, the change in upstream storage, and measured inflow to the Delta, we estimated the "upstream water use." This category includes consumptive water use for the year, any accretions or depletions (such as flow into or out of aquifers), upstream exports, and any errors in the estimates.[54] This approach gives an indication of the total water balance for the watershed. Figure B5 presents an overview of these results, including volumes apportioned to each use

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[48] In 1998, an extremely wet year, D1641 pumping limits had no effect because inflows were so high that exports were not limited under the export/inflow limits

[49] The sample size for this comparison is small (nine years) and dominated by the drought of 2012–16. Therefore, these averages are useful only as approximations of water assignments in different year types.

[50] These fractions result both from the increase in system and ecosystem water requirements since 1995 and the decrease in water diverted in dry periods.

[51] The estimate of required system water increased, so a constant system-water-to-total-water-used means that water diversions increased as well; this reflects increased water demands and use of wet periods to store water south of the Delta.

[52] This period reflects the improved availability of upstream storage and flow data, following the 1994 Bay-Delta Accord.

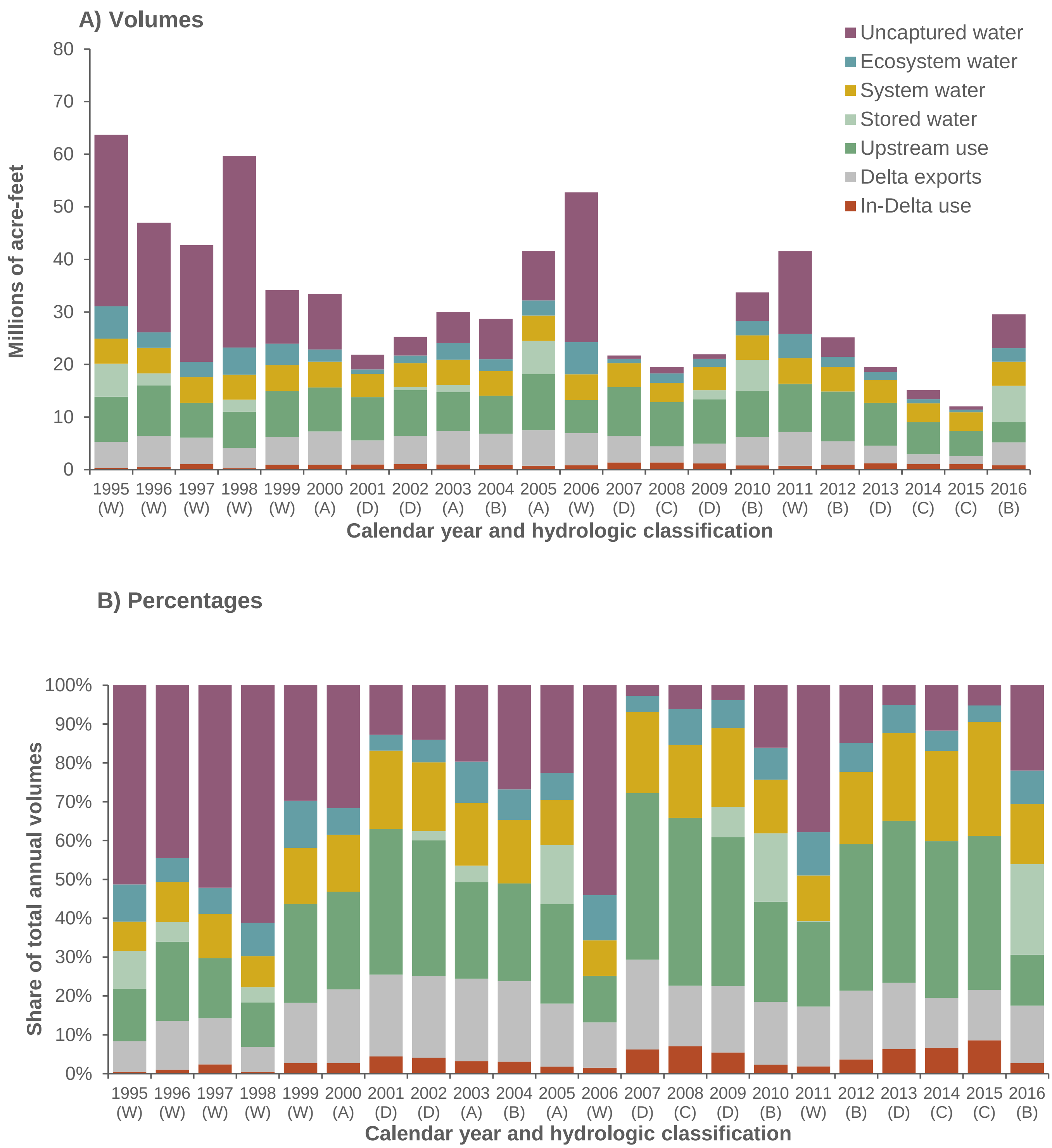
[53] Unimpaired flow estimates are from California Department of Water Resources. 2016a. Stored water estimates are from CDEC.

[54] Upstream exports include East Bay Municipal Utility District and San Francisco Public Utilities Commission exports of about 0.2 and 0.3 maf annually. See the EBMUD and SFPUC Urban Water Management Plans. Because total upstream use is calculated by difference, any errors or uncertainty in the flow or use estimates accumulate to the upstream use.

(panel A) and their shares of total water available (panel B). Years in which there was a net release of stored water—for upstream uses or Delta inflow—show no water for that year going to storage.

FIGURE B5

Total Sacramento–San Joaquin Valley water balance, 1995–2016



SOURCE: See Table B1, discussion in text, and *PPIC Delta Water Accounting*.

NOTE: Hydrologic classifications are based on D1641. W=wet, A=above normal, B=below normal, D=dry, C=critically dry.

These estimates reinforce the findings shown above. Water use in the watershed varied considerably over the past two decades, principally due to large changes in precipitation. Items to note:

- Uncaptured water is highly variable, representing approximately half of all water available in the watershed during wet years and less than 10 percent in drier years.
- Upstream water use is less affected by drought than Delta exports. This is because many upstream users have more senior water rights and better access to groundwater.
- With exception of the wettest years when there are very large uncaptured outflows, Delta exports and in-Delta use make up approximately 20 percent of the watershed balance.
- Upstream use, stored water, and diversions for in-Delta use and exports range from 30 percent of total water available in wet years to as much as 70 percent in drier years.
- System water is surprisingly consistent as a share of water available in the watershed, varying from a low of 20 percent in wet years to as much as 35 percent in dry years.
- In contrast, ecosystem water varies considerably, ranging from a high of 10 percent of all water available in the watershed in wet years to a low of four percent during dry years.

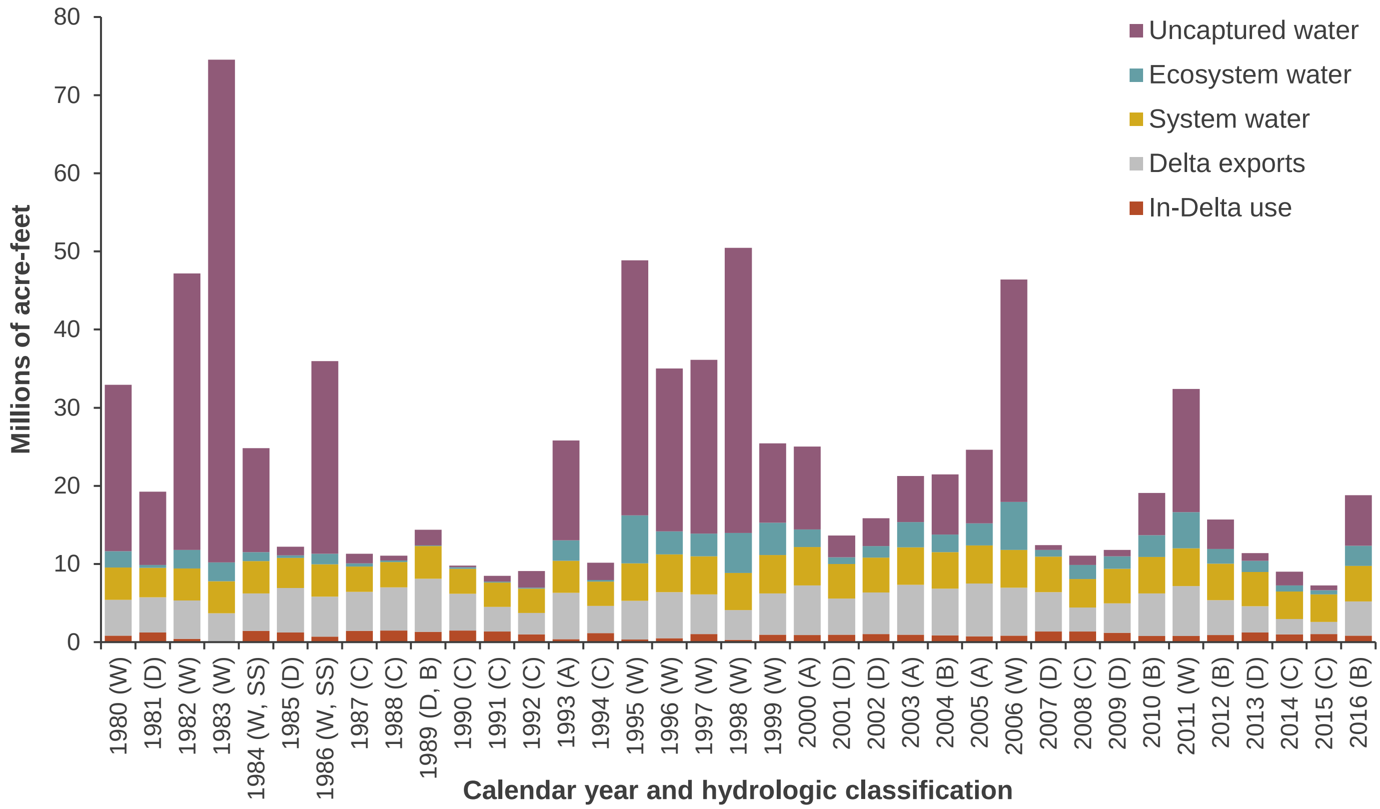
Discussion

In this study we have sought to improve accounting for environmental water in the Delta by assigning flow to specific uses that build upon one another. Here we describe some major takeaways of the analysis, briefly compare this approach with other studies, and highlight some areas where progress can be made in addressing uncertainties to strengthen environmental water accounting and regulatory oversight.

Major Takeaways from this New Accounting Approach

Figure B6 summarizes our accounting exercise for the entire 1980–2016 period. In-Delta uses and exports are primary, historical uses of water in the Delta, and large volumes of system water need to flow out of the Delta to repel salinity and keep water sufficiently fresh for these uses. This system water provides direct benefit to the ecosystem as well as water users, and should be viewed as achieving multiple purposes. But in the absence of any regulations to protect the Delta ecosystem, this water would still be needed to support diversions. System water is a very large and often underappreciated component of managed Delta outflow. During the recent drought, for example, the volume of system water often exceeded the volume of water used by diverters.

FIGURE B6
Where Delta water went, 1980–2016



SOURCES: See Table B1.

NOTES: Hydrologic classifications are based on D1485 (1980-1994) and D1641. W=wet, A=above normal, B=below normal, D=dry, C=critically dry, and SS=subnormal snowmelt (under D1485 only).

Multipurpose Water

We have taken a building block approach to account for water to meet ecosystem objectives on top of system flows. As noted, however, system water often helps fulfill ecosystem flow and water quality standards.[55] In every year there are also periods when the X2 standard for fish requires more water than required for system water (generally in the winter and spring), and periods when system water exceeds the flow standards for fish protection (generally starting around August). Figure B7 splits system water into two categories—multipurpose water that fulfills both system and ecosystem requirements, and system water that is required exclusively to meet diversion water quality standards. It also shows the additional water required to meet ecosystem flow and quality standards, presented in earlier charts. Under most conditions, multipurpose water is large relative to the amount of water assigned exclusively to system water or ecosystem flows and water quality. The exception is wet years since 1995, where the additional outflow required to meet ecosystem flow and quality standards is also quite large.

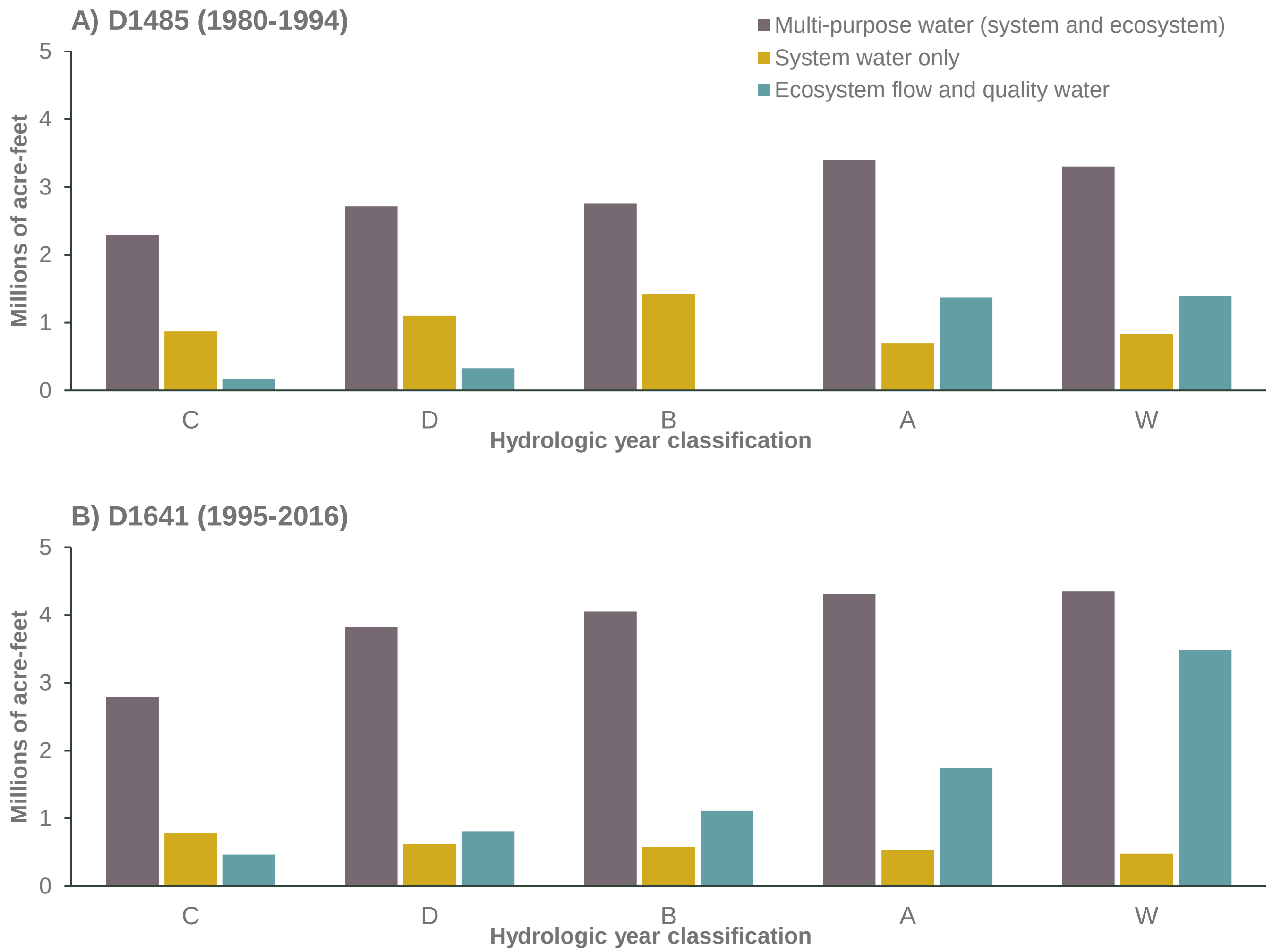
Figure B7 also shows a potential flaw in assigning water categories in this fashion. Under D1641, system water required to meet the same regulations went up, for reasons described above. But water that is exclusively for system water purposes is substantially lower under D1641, and multipurpose water is substantially higher. The increased multipurpose water reflects the increase in ecosystem water flow and quality requirements under

[55] This is not true for export pumping limits, which are assigned exclusively to ecosystem water.

D1641, which pushed more water into the multipurpose category. As this example illustrates, changes in regulations can cause unintuitive changes in the amounts of multipurpose water, making this method less transparent that the building block approach we have used.

FIGURE B7

Multipurpose, system, and ecosystem water under different year types, 1980–2016



SOURCES: *PPIC Delta Water Accounting*.

NOTES: Hydrologic classifications are based on D1485 and D1641 (W=wet, A=above normal, B=below normal, D=dry, C=critically dry). The figure does not show ecosystem water for export pumping limits, which cannot be met by system water.

Uncaptured Water

Uncaptured water is an additional component of Delta outflow that is often underappreciated. Uncaptured outflow—like other outflow—is often described as "water wasted to the sea." However, there are significant (and difficult to measure) direct benefits to the Bay-Delta ecosystem and Delta water users that come from these flows. High inflows freshen the Delta, pushing more saline water westward to Suisun and San Pablo Bays. This has well-documented benefits to the ecosystem and an array of native fishes, along with benefits throughout San Francisco Bay (Cloern et al. 2017). These uncaptured flows also benefit Delta water diverters by reducing the amount of inflow from upstream reservoirs needed to maintain acceptable salinity levels for extended periods even after the high flows subside.[56] For these reasons, we believe it is as important to systematically track uncaptured outflows as it is to track water use and system and ecosystem water.

Changes Over Time

This accounting approach also allows for a more substantive assessment of how Delta water has been reapportioned through time. One of our conclusions is that ecosystem water requirements have increased at two important points—first, in 1995 with the adoption of D1641 and the Delta Accord, and second in 2008 with implementation of the revised ESA BiOps. Before 1995, when D1485 was the main guiding regulation, ecosystem water increased only modestly with the volume of inflow (Figure B8, panel A). This reflected the way environmental regulations—principally focusing on striped bass—were crafted to minimize impacts on water diversions. This approach may have contributed to changes in Delta ecosystem conditions that have been detrimental to native fishes. Following implementation of D1641 and other ecosystem regulations from 1995 onwards, a well-defined relationship was established, where more inflow to the Delta was matched by more water assigned to the environment. The amount of ecosystem water increased again with the implementation of the post-2008 BiOps, but the regulatory relationship that closely tied inflows to assigned ecosystem volumes held.[57]

The potential increase in the cost of ecosystem regulations in terms of reduced Delta exports is illustrated well in Figure B8, panel B, which plots ecosystem water requirements against Delta exports. Before 1995, there was no clear relationship between the volume of diversions and the volume of ecosystem water. This reflected the relaxation of ecosystem flow and water quality regulations under D1485 when inflow or exports were limited, minimizing the interference of these regulations on CVP and SWP operations. Following implementation of D1641—and particularly from 2008 onwards—a well-defined relationship seems to exist (within the limits of the short record).[58] Recall, however, that with the exception of drier years when Delta water is tightly managed, the ecosystem water volumes are upper bounds. Actual cost to exports cannot be determined from this approach, but is likely to be substantially less in wetter years.

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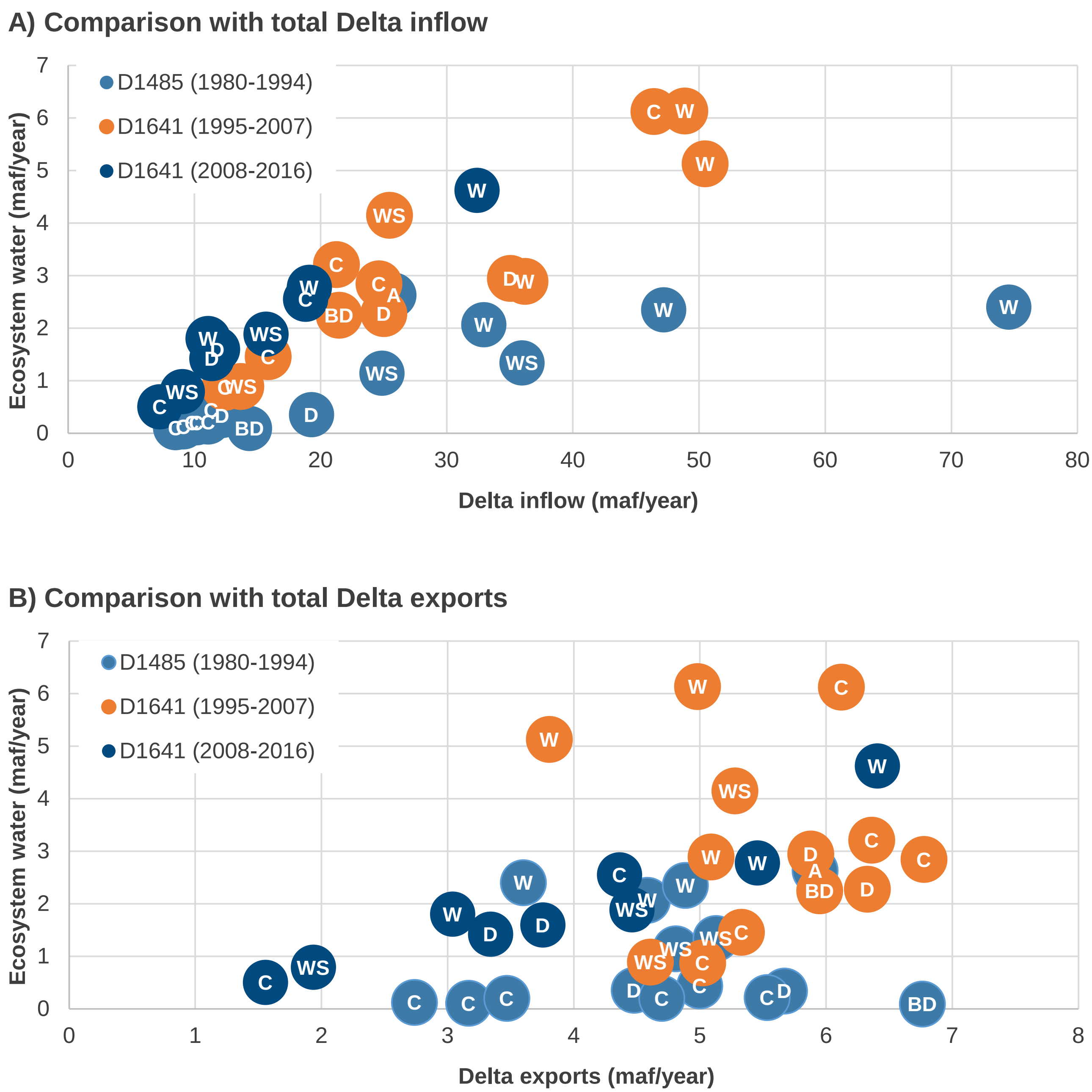
[56] For example, one often sees outflows falling well below the average needed to maintain the M&I water quality standard in late August. This is because the agricultural water quality standard, which can require much more outflow, stops on August 15. Exports are often increased to “harvest” as much water as possible, driving outflows lower than normally required. Outflows have gone negative during such periods, which means water is moving into the Delta from Suisun Bay.

[57] In comparing the post-2008 data with earlier years, it is most useful to compare the points vertically to get a sense of the increase in ecosystem water post-2008. The data also reflect the larger number of dry years post-2008, and the larger number of wet years in the earlier periods. We do not address whether this relationship is sufficient to meet the multiple objectives for ecosystem water in the Delta.

[58] The graphs reflect the hydrologic conditions of each period as well as changes in regulations. From 2008 onwards, there is just one wet year, versus six wet years from 1995–2007. Conversely, there are no critically dry years from 1995-2007, while the post-2008 period had three, along with several dry years.

FIGURE B8

Ecosystem water compared to total Delta inflow and water diversions



SOURCE: *PPIC Delta Water Accounting*.

NOTE: Hydrologic classifications based on D1495 (1980–94) and D1641 (1995–2016). W=wet, A=above normal, B=below normal, D=dry, C=critically dry, SS=subnormal snowmelt (under D1485 only), BD=below normal/dry, and WS=wet/subnormal snowmelt. The year 1989 followed a critically dry year, and therefore had a dry classification for ecosystem flows, and below normal for system flows.

Increasing Outflow Required to Meet System Water Needs

Finally, this analysis reveals an underappreciated—and to date unexplained—change in system water required to maintain salinities for water uses. Figure B9 illustrates the relationship since 1980 between system water and Delta inflows (panel A) and Delta exports (panel B). Since M&I and agricultural salinity standards under D1485 and D1641 are the same, this change—requiring an increase in system outflow of 400,000–600,000 af per year—

is a significant burden on the projects, which must release additional water from reservoirs to maintain salinity standards. The causes of this change require further investigation, but may be due to increases in Delta consumptive use that reduce outflow, changes in export operations that make it harder to maintain salinity standards, modeling errors, or hydrodynamic changes in the Delta (including the operation of the Montezuma Slough Salinity Control Structure, sea level rise, and other physical changes), discussed previously.

FIGURE B9

System water compared to total Delta inflow and diversions (in-Delta and exports)

SOURCE: *PPIC Delta Water Accounting*.

NOTE: Hydrologic classifications based on D1495 (1980–94) and D1641 (1995–2016). W=wet, A=above normal, B=below normal, D=dry, C=critically dry, SS=subnormal snowmelt (under D1485 only), BD=below normal/dry, and WS=wet/subnormal snowmelt

Comparison with Other Efforts to Account for Environmental Water in the Delta

This study is not the first to attempt to assess the impact of regulatory assignments on the apportionment of Delta inflows. Here we review some past analyses and discuss how they differ from ours. In general, these methods can be divided into those that seek to account directly for the assigned water required to meet regulations and those that account for the reductions in Delta exports resulting from these regulations. Although our approach falls into the first category, it differs in other ways, including whether the estimates are for the total volume of water required to meet a regulatory standard (our case) or the incremental water needed to meet the standard relative to some baseline (the case for several other studies). Studies also differ in the periods of analysis—which can limit comparability—and the extent to which they disaggregate environmental regulations. Ours provides a more detailed disaggregation of environmental water regulations than most other studies, and it is unique in using a building block approach to apportion this water into system and ecosystem purposes.

Table B4 summarizes prior studies and methods. We first provide a brief description of approaches taken by some earlier studies. We then 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).

TABLE B4

Previous studies quantifying water volumes required by regulations in the Delta

Source	Method used
Decision 1379 (State Water Resources Control Board 1971)	Assigned water, measured by the outflow needed to meet various requirements. Generally, greatly underestimated required outflow compared to current methods for salinity-outflow relationships.
Denton and Sullivan (1994)	Assigned water for potential new fish and wildlife water quality standard (X2). Analyzed for 1968-1991, but only for the increment above the then-current operational requirements. No attempt was made to characterize the baseline volume of assigned water in existing requirements.
DWR Delivery Capability Report (2015)	Done every two years, measures the delivery capability of the SWP. By comparing results from different years, one can determine the approximate effect of changing regulatory requirements on export delivery capability since about 2003.
CVPIA accounting of upstream and downstream Delta water for §3406 (b) 2 water (US Department of the Interior 2003)	Method specific to the water assigned under the CVPIA for salmon (800,000 af in most years), it counts water released from reservoirs (upstream water), or pumping reductions or other actions in the Delta, such as the cost of closing the Delta Cross-Channel on pumping (downstream water).
California Water Plan Update (Department of Water Resources 2013)	Estimates total Delta outflow due to ecosystem requirements of D1641 for 1998–2010.
MBK Engineers and HDR (2013)	Uses CALSIM II model for historical hydrologic conditions, with operations governed by D1641 and D1641 with post-2008 ESA compared to D1485. Analyzes delivery capability of the SWP and CVP.

An Overview of Earlier Approaches

D1379 and related efforts. Bulletin 27 (California Department of Public Works 1931) and the Appendix to DWR Bulletin 76 (California Department of Water 1962) provide early estimates of the outflow required to meet water quality objectives at various locations in the Delta. SWRCB's Decision 1379, published in 1971, appears to have relied upon some of these estimates, but the document does not explain exactly how the estimates were derived or how they were used in estimating the amount of water assigned to meeting the D1379 salinity requirements.

The methods used give average salinity-outflow relationships at various locations in the Delta which are substantially below the outflow levels now believed to be necessary. For example, DWR Bulletin 76 reports that USBR believed that an outflow of 1,500 cfs was sufficient for adequate water quality at the Tracy Pumping Plant.[59] Current estimates put the outflow at twice that amount.

In contrast, SWRCB's Decision 1485 (1978) does not discuss the amount of water assigned to the salinity and flow standards. The only discussion of water volumes is a notation that the "firm exportable yield" of the CVP and SWP was the primary measure of the projects' ability to meet firm export demands, and that D1485 standards would have increased that ability in the 1928–1934 drought by 160,000 af over the standards in place under the Bay-Delta Basin Plan in effect at the time (which had more restrictive objectives). This is a signal of the shift of measuring standards from the amount of assigned water to the impact of standards on the ability of the projects to deliver water. This shift can be attributed to the development of computer models that could more easily model the operations of the projects under various scenarios, and the improved ability to measure salinity and outflow.

Denton and Sullivan (1994). Denton and Sullivan examined the additional flow required to meet the X2 standard—which provides more freshwater for fish during the spring—and various alternative proposals, when the X2 standard was being considered by the US Environmental Protection Agency and the SWRCB. The final version of the X2 standard built on the methods they considered.

Their analysis used historical Dayflow data from 1968 (the year the SWP began pumping from the south Delta) to 1991. However, they focused not on the total water assigned to the X2 standard, but only the additional water required above historical outflow. Consequently, this method is similar to, but not the same as the one we are using here. We are documenting the total water assigned to meeting water quality and flow standards, not additional water over some baseline, and we use a different time period (1980–2016).

DWR's biennial Delivery Capability Reports. Since 2003, the Department of Water Resources has produced a Delivery Capability Report every two years, with the most recent one released in 2015.[60] These reports use the latest regulations that must be met by the CVP and SWP to meet standards in the Delta to determine the delivery capability of the SWP. The analysis uses the CALSIM model over a long historical hydrologic period, and some projections take into account future anticipated climate change effects such as sea level rise. By comparing the long-term results from different studies published since 2003, the effects of changing regulatory requirements on export delivery capability can be approximated.

CVPIA Accounting of Upstream and Downstream (Delta) Water. The CVPIA required that 800,000 af of CVP yield be assigned to environmental purposes. The method used to assign this water resulted from a long series of discussions and negotiations, followed by lawsuits and a court decision (US Department of Interior 2003). Among the items that are charged to the accounting are export pumping reductions for VAMP, ESA, or other CVPIA purposes, and sometimes reductions required by D1641.[61]

The method has two parts: "upstream actions" and "downstream actions." The downstream component falls into the class of methods that seek to measure reductions in Delta export pumping from environmental regulations. The upstream actions approach—which measures reservoir releases above a baseline—is different from all the other approaches described here, because it focuses on environmental water flows in a different part of the

[59] California Department of Water Resources. 1962. "Salinity Incursion and Water Resources, Appendix to Bulletin 76," p. 64.
[60] The 2015 report is found here. Earlier versions are also available online.
[61] In practice, there is some discretion, as can be seen from a review of B2 annual reports. See for example the 2010 summary.

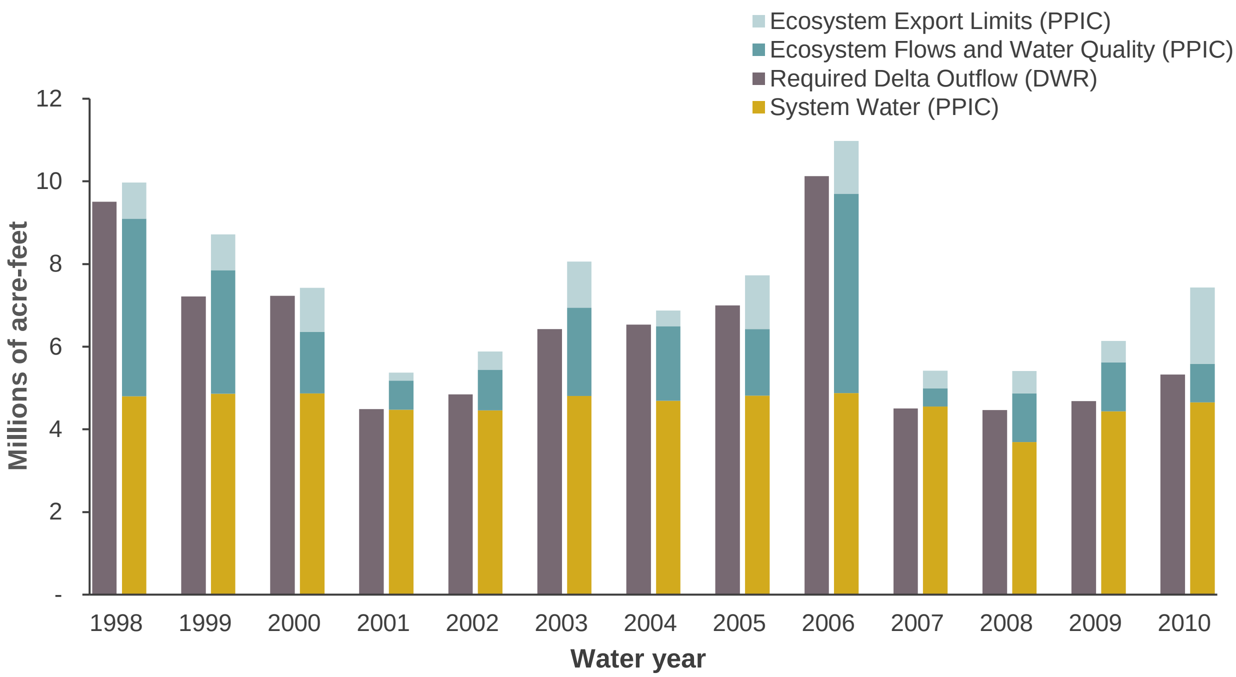
watershed. (See the discussion of this approach and related measurement issues in the caveats and limitations section above.)

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 B10 compares our estimates with DWR's for the years when both series are available (1998–2010).[62] To facilitate comparison, we have broken down our estimates into system water and two categories of ecosystem water: flow and water quality requirements, and export pumping limits.

FIGURE B10

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



SOURCES: California Water Plan Update (Department of Water Resources 2013) and *PPIC Delta Water Accounting*.

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.[63] 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.

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[62] DWR uses water years for its accounting (October through September). For this comparison, we have adjusted our results to match DWR's approach.

[63] 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 carryover 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 noted earlier, and shown in Figure B7, fall system water needs are often slightly higher than ecosystem flow and water quality needs.

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.

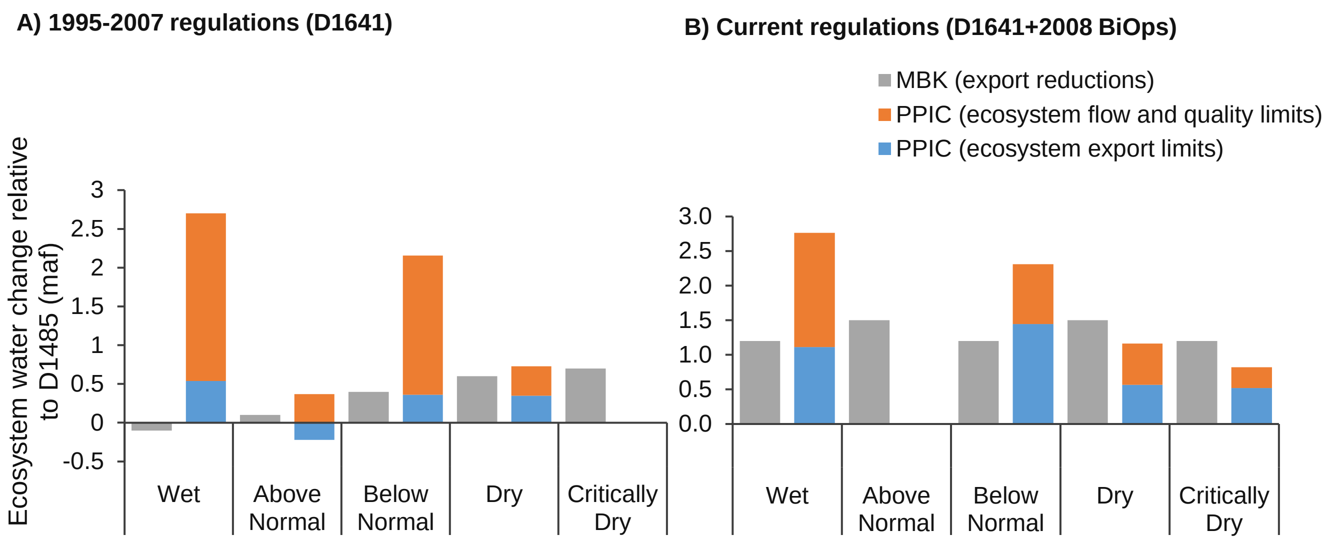
Comparison with MBK Engineers' estimates of regulation costs to Delta exports

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.[64] 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. Because regulations 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.

In Figure B11 we compare MBK's estimated reductions in exports with our estimates of changes in ecosystem water under the D1641 and ESA regulations in effect from 1995–2007 (panel a) and under regulations in effect since 2008 (panel b). 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 B11 displays these as the bottom category in the stacked bars.

FIGURE B11

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 PPIC estimates are for a smaller set of actual years, whereas the MBK estimates are simulated results for a longer hydrologic record (see text). Table 1 presents the PPIC estimates used here. 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.

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[64] *Retrospective Analysis of Changed Central Valley Project and State Water Project Conditions Due to Changes in Delta Regulations* (MBK Engineers and HDR 2013) looks at the effects of D1641 and ESA regulations on the delivery capabilities of the SWP and CVP while keeping upstream regulations unchanged, thereby studying only the changes in Delta regulations since implementation of D1485. The analysis used a similar method to DWR's Delivery Capability Report, and the same simulation model, CALSIM.

This comparison yields several key conclusions:

- Both studies show increases in ecosystem water requirements relative to the period when D1485 was the primary regulation.
- 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, under post-2008 regulations, 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, the MBK study (along with related economic analyses) overstates the impacts of environmental regulations on exports during drier years.
- In wetter years (including those classified as "below normal"), our estimates of ecosystem water increases are much larger than MBK's estimates of export losses. However, under post-2008 regulations, 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 such years, and such restrictions rose with the 2008 update of the BiOps.

Addressing Uncertainties to Improve Assigned Water Accounting

The preceding analysis has shown the evolution of assigned water as regulations changed over the past 37 years. It underscores the complications that arise when trying to ascribe a given volume of water to a specific purpose, particularly when that water achieves multiple benefits or meets multiple regulatory purposes.

However, the separation of system water from ecosystem water—rather than the more general "environmental water" in the state's current method for Delta water accounting—may afford an opportunity for more precision and insight in tracking how ecosystem water is used. It may also help guide the development of new regulatory standards to facilitate better water management. And, as discussed in a companion report (Mount et al. 2017), it can be the foundation for discussion over volumes of water to be allocated to an ecosystem water budget.

Regardless of the method chosen, better accounting is needed if this approach is to be adopted

- **Outflow estimates.** Whenever water is assigned for outflow, the amount is subject to how that outflow is determined. There is a need to reduce uncertainty in these estimates, which are developed with inflow measurements (using gages on major rivers), reported pumping (only a few pump stations report), measured precipitation at one station (then assumed to be the same over the 700,000 acres of the Delta), and monthly estimates of Delta consumptive use (which varies with the weather, crop patterns, and other factors).[65] The current method is prone to double-counting and missing factors.[66] These problems are recognized and can be addressed, but some error will always remain.[67]
- **Salinity requirements.** Assigning water to meet salinity requirements is also subject to uncertainty in the outflow needed to meet a standard. The actual outflow at any time depends on the outflow history, tides, weather, as well as changes in Delta channels, flooded areas, and sea level. Over weeks or months, the amount can be estimated with a reasonable degree of accuracy, but it is still subject to change as factors change over time.

[65] See Medellín-Azuara et al. (2016) for a comparison of results of different methods and models estimating consumptive use in the Delta.

[66] For an example of double-counting, Contra Costa Water District delivers water to a number of customers who have their own water rights. At times they do not exercise those rights because the water at their intakes is too saline, so they take it from the Contra Costa Canal. The Delta consumptive use estimates used in the daily accounting include the average use for those intakes, but they are also included in CCWD pumping at times; in those instances, they are double-counted. The error is small, but not zero. For an example of missing factors, several discharges from wastewater treatment plants are not included, as they did not exist or their capacities have greatly expanded since the Delta consumptive use estimates were made.

[67] For example, it is difficult to get better than 5 percent accuracy on flow meters.

- **Export pumping limits.** Assigning water through pumping limits depends upon the capacity of the pumping plants (which can change) and the amount of water available to be pumped, which is subject to many factors. Those factors include the hydrologic conditions of the moment and the past months, the amount of water released from storage (which can depend upon flood control rules and instream flow requirements), and upstream diversions and uses. Calendar-dependent pumping limits can inadvertently allocate a large volume of uncaptured water to the environment if it rains and there is suddenly a large uncaptured flow that becomes "off limits" to pumping.
- **Upstream contributions to Delta outflow.** Accurate accounting becomes more complicated if regulators seek to assign water to outflow from upstream sources, including snowmelt and reservoir releases. Reservoirs are often operated cooperatively: increased or decreased releases in one reservoir can be offset by changes in releases in another. And water released is subject to diversion by water-right holders if it is not protected, and when it arrives in the Delta it is subject to Delta regulations. For these reasons, there must be a mechanism to account for water during the time it is in the river, and to regulate other reservoirs on the system and all water right-holders. This would require reporting and accounting on a scale not yet attempted. Even then, there are uncontrolled factors related to the interaction of the rivers with groundwater, and weather conditions.
- **Fixed ecosystem water allocations.** Assigning a fixed amount of water to the ecosystem in advance is also challenging. For example, the X2 standard determines the amount of Delta outflow required monthly to protect fish, based on the prior month's runoff. But even that can run into problems in extremely dry years, as it did in 2014 and 2015. In those years, the minimum flow to maintain X2 (7,100 cfs) was so high compared to the available runoff that it would have required releasing large amounts of water from drought-depleted reservoirs. That water was believed to be necessary later in the year to support temperature requirements in the upper Sacramento River for winter-run Chinook salmon.[68]

These issues highlight how challenging it is likely to be to assign water to the ecosystem, to separate ecosystem from system water, and to forecast and prescribe its use. Yet, these issues are known and can be addressed with improved accounting and reporting (Escriva-Bou et al. 2016). The high price of water, especially in droughts, ensures that accounting for ecosystem water will become increasingly important.

Conclusion

Inflow to the Sacramento–San Joaquin Delta is managed for multiple objectives. These include water supply for in-Delta users, exports to the CVP and SWP contractors, and support for the Delta ecosystem. A significant portion of the Delta inflow must leave as outflow to maintain flows and low salinities sufficient for these uses.

Over the past several decades, regulatory standards for flow and water quality, along with restrictions on export operations, have changed substantially. Key factors include the SWRCB's adoption of new Water Quality Control Plans—D1485 in 1978 and D1641 in 1995—along with the implementation in the 1990s and 2000s of new federal laws and regulations including the Central Valley Improvement Project Act, the Vernalis Adaptive Management Program, and new Biological Opinions for salmon and delta smelt under the federal Endangered Species Act. Most of these changes seek to improve Delta ecosystem conditions to benefit native fishes—many listed under state and federal Endangered Species Acts. These changes have resulted in increased Delta outflow, and both potential and actual reductions in water available for exports.

We have tracked the amount of water assigned to meet regulatory standards in the period 1980–2016, along with in-Delta diversions and exports and uncaptured outflows. We have differentiated two types of assigned water in the Delta: system water needed to maintain flow and salinity sufficient for exports and in-Delta uses; and

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[68] As described in a case study on Shasta Dam operations during the drought, in the end USBR was unsuccessful at managing those temperatures in both years (Mount et al. 2017, Technical Appendix).

ecosystem water that must be added on top of system water to meet regulatory standards for native fish habitat. Ecosystem water comes from Delta inflows as well as restrictions on timing and amount of export pumping.

Our results show that assigned system and ecosystem water increased with implementation of D1641 and other regulatory changes beginning in the mid-1990s, with the largest increases in ecosystem water. Whereas system water volumes change only moderately with hydrology (3.5 maf per year in dry years to 4.8 maf per year in wet years), ecosystem water varies dramatically (recently ranging from 0.5 maf to over 6 maf per year). System water continues to require a larger volume of water than ecosystem water except in the wettest years. Combined, water assigned for these regulatory purposes has recently ranged from about 4–11 maf per year, versus 2.9–7.7 maf per year for in-Delta uses and exports.

The following rules of thumb apply to assigned water under current (post-2008) regulations:

- In drier years, 1.3 acre-feet of outflow was assigned for each acre-foot of water used in, or exported from, the Delta. This is 1.0 acre-feet of system water and 0.3 acre-feet of ecosystem water. This represents an increase of 0.4 acre-foot of system water and 0.3 acre-foot of ecosystem water per acre-foot diverted relative to 1980–94.
- In the one wet year included in our post-2008 sample (2011), it took about 1.5 acre-feet of outflow for each acre-foot of water used in or exported from the Delta. This is approximately 0.8 acre-foot of system water and 0.7 acre-foot of ecosystem water, and it represents a constant ratio of system water and an increase of 0.35 acre-foot of ecosystem water per acre-foot diverted relative to 1980–94.

These ratios of outflow to water used would be lower if water use upstream of the Delta is also considered.

We have emphasized that assigned water does not equate to the cost of these regulations in terms of reduced water available for Delta exports or in-Delta users. Our estimates of assigned water are often higher—sometimes considerably so. In many years, runoff from precipitation and snowmelt is sufficient to meet salinity and flow requirements, reducing the need for reservoir releases or pumping reductions. In addition, in wetter years, project operators can shift timing of export pumping to make up for pumping limits. The values of assigned system and ecosystem water are probably closest to actual cost to water exports during drier years, when uncaptured flows are low. The increase in export pumping limits since 2008 has likely increased costs to exports in other years as well.

These results yield several important policy implications:

- Delta outflows serve a variety of purposes. The largest share of required outflow has multiple benefits.
- A large fraction of the required outflow is necessary to maintain water quality for export and in-Delta uses. Athough much of that flow also helps meet ecosystem regulations, it would be required even if there were no ecosystem objectives in the Delta.
- Ecosystem outflow during the recent drought was a small fraction of the flow required to maintain Delta water quality.
- Better accounting of all flows and uses will be necessary to manage water supplies efficiently.

Estimates of assigned water have many measurement and analytical uncertainties. But this approach—which was developed with limited staff resources and using publicly available data and models—offers the potential for greater transparency in tracking the use of water for the ecosystem and promoting a common understanding in ecosystem water allocation.

REFERENCES

CALFED Bay-Delta Program. n.d. archived documents. For a summary of EWA, see: http://calwater.ca.gov/content/Documents/library/FactSheet_EWAWhitePaper_1-22-03.pdf.

California Department of Public Works. 1931. *Variation and Control of Salinity in the Sacramento-San Joaquin Delta and Upper San Francisco Bay*.

California Department of Water Resources. 1962. "Salinity Incursion and Water Resources, Appendix to Bulletin 76", see especially, p 64ff., p. 108, Table 22, and Plate 12.

California Department of Water Resources. 1995. *Estimation of Delta Island Diversions and Return Flows.*

California Department of Water Resources. 1997. *State Water Project Annual Report of Operations 1991* (p.19). (See http://water.ca.gov/swp/operationscontrol/annual.cfm for other reports of annual operations.)

California Department of Water Resources. 2001. Methodology for Flow and Salinity Estimates in the Sacramento–San Joaquin Delta and Suisun Marsh.

California Department of Water Resources. 2013. *California Water Plan Update.*

California Department of Water Resources. 2015. "The State Water Project Final Delivery Capability Report 2015" memorandum.

California Department of Water Resources. 2016a. "Estimates of Natural and Unimpaired Flows for the Central Valley of California: Water Years 1922–2014" (Draft).

California Department of Water Resources. 2016b. "Final TUC Order Accounting: February through November 2015."

California Department of Water Resources. n.d. California Data Exchange Center.

California Department of Water Resources. n.d. Dayflow data.

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).

Denton, R. 1993. "Accounting for Antecedent Conditions in Seawater Intrusion Modeling—Applications for the San Francisco Bay-Delta." Hydraulic Engineering 93, Vol. 1 pp. 448–453. *Proceedings of ASCE National Conference on Hydraulic Engineering, San Francisco.*

Denton and Sullivan. 1993. "Antecedent Flow-Salinity Relations: Application to Delta Planning Models" Contra Costa Water District.

Denton and Sullivan. 1994. *Report on Clean Water Act X2 Water Quality Standards*.

Denton, R.. 2006. "Refining CCWD's Salinity-Outflow Model—Presentation to the DSM2 Users Group."

East Bay Municipal Utility District. 2015. Urban Water Management Plan 2015.

Escriva-Bou, A., H. McCann, E. Hanak, J. Lund, and B. Gray. 2016. *Accounting for California's Water*. PPIC

Gartrell, Greg. 2014. "Where Did All that Water Go? Some Dry Numbers on Today's Drought." *California WaterBlog*. March 23.

Jackson and Patterson. 1977. *The Sacramento–San Joaquin Delta, the Evolution and Implementation of Water Policy* (see especially the discussion starting on page 108).

Johnston, William. 1998. "The San Joaquin River Agreement and the Vernalis Adaptive Management Plan." USCID Conference on Shared Rivers.

Lund, Jay. 2016. "How Much Water was Pumped from the Delta's Banks Pumping Plant? A Mystery." *California WaterBlog*. September 26.

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

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*.

Medellin-Azuara, Josué, Kyaw Tha Paw U, Yufang Jin, Quinn Hart, Eric Kent, Jenae' Clay, Andy Wong, Andrew Bell, Martha Anderson, Daniel Howes, Forrest Melton, Tariq Kadir, Morteza Orang, Michelle Leinfelder-Miles, and Jay Lund. 2016. *Estimation of Crop Evapotranspiration in the Sacramento San Joaquin Delta: Preliminary Results for the 2014-15 Water Year. Interim Report for the Office of the Delta Watermaster*. UC Davis Center for Watershed Sciences.

Monismith, Stephen. 2016. "A Note on Delta Outflow." *San Francisco Estuary and Watershed Science*.

NOAA National Marine Fisheries Service. 2009. "Biological Opinion and Conference Opinion on the Long-term Operations of the Central Valley Project and State Water Project."

San Francisco Public Utilities Commission. 2015. *Urban Water Management Plan 2015*.

San Joaquin River Technical Committee. 2008. *Summary Report of the Vernalis Adaptive Management Plan (VAMP) for 2000–2008* (Chapter 1).

State Water Resources Control Board. 1971. *Delta Water Right Decision 1379*. See also the related "Order" at the beginning of this document clarifying and correcting the decision, which corrected some calculations of the assigned water.

State Water Resources Control Board. 1978. *Water Right Decision 1485.*

State Water Resources Control Board. 1999. *Water Right Decision 1641*. Standards discussed here are summarized in Tables 1-4, pages 181–191.

State Water Resources Control Board. 1999. *Revised Water Right Decision 1641*.

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

US Bureau of Reclamation. 2016. "Mid-Pacific Region, Monthly Delta Operations Reports October–December of 2016."

US Bureau of Reclamation. 2016. Mid-Pacific Region, B2 Accounting. (See for example report for 2010.)

US Department of the Interior. 2003. *Decision on the Implementation of Section 3406 (b)(2) of the Central Valley Project Improvement Act.*

US Fish and Wildlife Service. 2009. *Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP).*

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