DELTA PLAN SUMMARY AND NEW SCIENTIFIC FINDINGS FOR DELTA PLAN UPDATE IN STORAGE, CONVEYANCE, AND OPERATION

The current Delta Plan, adopted in 2013, was based on the best science and information available at the time. Since adoption of the Plan, new information has been generated. The following is a summary of scientific information contained in the current Delta Plan (2013) relevant to water supply, including storage, conveyance, and their operation, the ecosystem, and climate change. Updated information about each is then provided at the end of each Delta Plan topic summary.

WATER SUPPLY

Summary of the 2013 Delta Plan

The Delta is the terminus for the largest watershed in California and is the hub of the State's water supply system. Some of the water flowing from the Delta watershed is diverted before it reaches the Delta (approximately 31%), is used in the Delta (about 4%), and is also exported from the Delta via the Central Valley Project (CVP) and the State Water Project (SWP). The amount exported varies from year-to-year depending on whether it is a wetter or drier year, but on average it represents about 24% of Delta inflows.

The CVP and SWP were originally engineered to deliver water to water contractors and water rights holders with little consideration or understanding of the potential impacts to the environment. Operation of the system in this manner resulted in a decline of key Delta ecosystem health indicators. With the passage of environmental laws in the 1970s, their operation began to be regulated by various entities including the State Water Resources Control Board (SWRCB) for water quality and inflow standards, the U.S. Army Corps of Engineers (USACE) setting "rule curves" for reservoir operation for flood protection, and due to species listed as threatened and endangered by the California Department of Fish and Wildlife (CDFW), the U.S. Fish and Wildlife Service (USFWS), and the National Marine Fisheries Service (NMFS). The challenges today are to deliver water from the Delta to meet California's water needs without further degradation (and/or risk of degradation) of the Delta ecosystem.

On average, exports from the Delta have increased during the last 40 years with record exports occurring during the 10 years (2002-2011 according to Figure 3-5) prior to adoption of the Delta Plan. Yet factors such as land subsidence on agricultural Delta islands, rising sea level, the threat of earthquakes, fish entrainment at the pumps, fish migration issues due to reverse flows in the southern Delta, and salinity increases due to reduced outflows to San Francisco Bay continue to plague the system. Due to environmental regulations to protect drinking and irrigation water quality as well as other beneficial uses, combined with increased delivery demands, CVP and SWP have rarely delivered 100% of the contracted water allocations since 1990. This has resulted in many complex and often bitter legal conflicts among water users. The greatest conflicts occur during dry years when regulations constrain exports to protect drinking and irrigation water quality from excessive salinity and other public trust resources.

Update (2015)

Current water supplies have been affected by four years (2012-2015) of drought and warmer temperatures, both associated with a changing climate (Williams et al. 2015). This has resulted in increased groundwater pumping which in turn, resulted in increased land subsidence (currently, 2 inches per month in the Central Valley) (Farr et al. 2015) and substantially higher energy costs for water supply (Medellín-Azuara et al. 2015). Climate change will bring altered precipitation patterns thereby affecting the hydrology in California's streams and rivers (Van Lienden et al. 2014). Due to a warming climate, more precipitation is occurring in the form of rain rather than snow and evapotranspiration (return of precipitation to the atmosphere via evaporation and transpiration) is increasing resulting in additional water losses (Pierce and Cayan 2013). All these factors influence California's water supply.

- Groundwater has been depleted in California, especially in the Central Valley where from October 2003 to March 2010, 20.3 km^3 of groundwater was depleted (Famiglietti et al. 2011). The recent drought resulted in increased groundwater pumping in the Central Valley to replace reduced surface water deliveries. Estimated additional pumping costs with a base 2012 condition are $447.6 and $590 million in 2014 and 2015, respectively, and even higher pumping costs are expected if the drought continues (Hanak et al. 2015; Howitt et al. 2015; Medellín-Azuara et al. 2015). If the current drought in California continues, the greatest vulnerabilities are in low-income rural communities and in California's wetlands, rivers, and forests (Hanak et al. 2015).
- Changes in precipitation patterns and vegetation distribution patterns due to warming will result in altered hydrology in streams and rivers. It is also expected that the spring peak flow would come earlier in the season due to more rain and earlier snow melting. A climate change scenario with a temperature rise of 2.4 °C and an average 40% decrease in the relative proportion of snowfall is projected to result in a 12% reduction in overall stream flow (Berghuijs et al. 2014).
- In California, evapotranspiration (ET) comprises the largest consumptive use of California Department of Water Resources (CDWR) (Central Valley Project) project water, excluding water needed to maintain water quality and environmental needs. Climate change could potentially affect ET in several complex ways, which makes it challenging to quantify overall changes in ET. Increasing air temperature by 3 °C with current CO_2 concentrations (360 ppm) is estimated to yield an 18.7 % increase in ET in the Central Valley Basin (Anderson 2008).
- A recent study using the current precipitation regime in Kings River Basin (California) and a mean projected temperature increase of 1.3 – 4.1 °C by the year 2100 found that that there would be a 10-28% increase in ET and 9-26% decrease in stream flow (Goulden and Bales 2014).

STORAGE

Summary of the 2013 Delta Plan

Increased storage, both above and below ground, could increase flexibility in the system and enable the delivery of water as needed for environmental, agricultural, urban and industrial uses. Water storage capacity is inadequate, especially south of the Delta, to facilitate export of water at times of surplus. In 2010 when water was available and requirements for water quality and endangered species were met, SWP and CVP pumps were slowed because surface storage south of the Delta was already full. Since 1995, smaller surface storage improvements, including Diamond Valley, Seven Oaks, Olivenhain, and Los Vaqueros reservoirs, added 1.2 million acre-feet (MAF) of surface storage. At the time the Delta Plan was adopted, Sites Reservoir, Los Vaqueros Reservoir expansion, and Temperance Flat Reservoir were being evaluated by CDWR to add more surface storage.

Assessment of the state's groundwater storage in 2000 identified more than 21 MAF of potential groundwater storage in Southern California and the southern portion of the San Joaquin groundwater basin. Groundwater elevation reporting became mandatory by the California Statewide Groundwater Elevation Monitoring Program created in 2009. Groundwater basins, as a result of continuous use exceeding recharge, are in overdraft in many regions in California. Without more efficient management, some of the state's groundwater storage capacity can be permanently lost as a result of severe overdraft.

Storage improvement opportunities are available via system reoperation, small-scale storage projects, and conjunctive water management and water transfers. CDWR is leading a System Reoperation Task Force with the Bureau of Reclamation, USACE and other State, federal and local agencies to assess opportunities for reoperation of existing reservoirs and conveyance facilities to improve flood protection and capture available runoff. Many local storage and conjunctive management projects were identified through competitive State and federal grant funding application processes in the past decade, though many of them could not be funded due to limited funding and restrictions in grant provisions.

Update (2015)

Climate change will intensify the spatial imbalance between water supply availability (precipitation) and demand in California. Recent research suggests that the supply of available water in the future could be further reduced under a climate change scenario that includes changes in precipitation patterns (variations in snow and rain) and expansion of the vegetation range (Berghuijs et al. 2014; Goulden and Bales 2014). Extraction of groundwater in the Central Valley region has reduced both the groundwater level and underground storage capacity due to subsidence (Famiglietti et al. 2011; Weiler 2014). Prudent strategies for storage enhancement and operation of water storage facilities (both surface and underground) are needed to prepare for the upcoming changes in water supply conditions.

- California accumulated a precipitation deficit of 20 inches during the current drought (2012 - 2015), which is equivalent to the average amount expected to fall in the state in a single year. This deficit was driven primarily by a lack of air currents rich in water vapor moving inland from the Pacific Ocean (Savtchenko et al. 2015).
- Anthropogenic warming is increasing the probability of co-occurring warm and dry conditions. The current California drought is mainly driven by the lack of precipitation but increased greenhouse gases have contributed to the probability that dry precipitation years will also be warm (Differbaugh et al. 2015; Mann and Gleick 2015; Williams et al. 2015).
- Annual precipitation amounts are projected to be quite variable over the next century with a slight increase (0.6%) in the Sacramento Basin and a decrease (4.2-5.3%) in the San Joaquin Basin by 2050 (Van Lienden et al. 2014). With increasing air temperature, the relative proportion of precipitation falling as rain instead of snow will increase during wintertime (Pierce and Cayan 2013), which will increase wintertime runoff and subsequently decrease summertime runoff. Under a mild climate warming scenario (2°-3°C by 2099), the Sierra Nevada region is projected to have up to a 30% (±3.7% error) reduction in the amount of water contained in the snow-pack by April 1, 2099 as a result of precipitation pattern changes during the cold-season (October-March)) (Pierce and Cayan 2013).
- More rain than snow with reduced snow pack is predicted by most climate change models. Less spring runoff will make balancing reservoir management for flood control and water supply more complicated (PPIC 2015).
- Using current management practices and existing system facilities, shifts in precipitation and runoff will directly affect deliveries and reservoir storage levels for the SWP and CVP. Lower carryover storage is projected for both SWP and CVP, which indicates the projects are operating at a higher water supply risk and lower head for hydropower production and less cold water pool storage for fish protection. The warmer climate and significant shift in seasonal runoff will result in consistently lower water delivery capability (Anderson et al 2008).
- End-of-September storage (carryover storage) will decrease due to climate change in the 21st century (CDWR 2009). CDWR predicts that by the end of the 21st century the median end-of-September storage in Lake Shasta, Trinity Lake, Lake Oroville, and Folsom Lake, in terms of quantity, will be reduced by 33% (95% confidence range: 21-45%) and 38% (95% confidence range: 24-51%) in IPCC Climate Change Scenarios B1 (low greenhouse gas emission scenario) and A2 (high emission scenario) by the end of the 21st century (CDWR 2009).
- A major contribution to California's water shortage is the declining snowpack in California's Sierra Nevada range as shown by data from NASA's Airborne Snow Observatory (ASO). The loss of snowpack is particularly worrisome because it deprives California of the natural reservoir that usually helps the state make it through the dry

periods. This trend may be hard to recover from because the loss of snow exposes darker mountain terrain, which absorbs more heat from the sun and makes it harder for future snows to develop and persist (Thomas Painter, cited by Weiler 2014). The snow water equivalent in the Sierra Nevada mountains on April 1, 2015 was only 5% of its historical average and was unprecedented in the context of the past 500 years (Belmecheri et al. 2015).

- Analysis of satellite data (GRACE: Gravity Recovery and Climate Experiment) reveals that California needs 11 trillion gallons of water (33.7 MAF or 42 cubic kilometers) to end its ongoing drought. The data show that two-thirds of the loss represents groundwater depletion in California's Central Valley and this reflects an unsustainable use of water resources by the state. In the past five decades, groundwater levels in the Central Valley have declined sharply during dry years and recovered only slightly during wet years as water was diverted for agriculture and municipal use (Jay Famiglietti, cited by Weiler 2014).
- From 1922 to 2009, groundwater storage declined by approximately 130 MAF (Brush et al. 2013) or approximately 1.5 MAF per year in the Central Valley. This value is similar to the 1.4 MAF per year net storage loss in typical years estimated by Faunt (2009). Estimated additional groundwater pumping in the Central Valley during the drought was estimated to be 5.0 MAF and 6.0 MAF in 2014 and 2015, respectively. More than half of the additional pumping in 2014 and 2015 was from the Tulare Basin (Medellín-Azuara et al. 2015; Howitt et al. 2015).
- Currently, more than 50% of monitored groundwater levels are at or below record historical spring-low levels including the Sacramento River (18 basins), South Coast (10 basins), San Joaquin River (5 basins), and San Francisco Bay (2 basins) Hydrologic Regions. Subsidence is occurring in southern San Joaquin River (4 basins), Tulare Lake (7 basins), Sacramento River (3 subbasins), and Central Coast (2 basins) Hydrologic Regions (CDWR 2014c).
- In August 2015, CDWR (CDWR 2015, draft document) listed 21 groundwater basins/subbasins as "Critically Overdrafted Basins". These include 5, 6, and 2 basins/subbasins in the San Joaquin River, Tulare Lake, and South Coast Hydrologic Regions, respectively.
- Increasing storage capacity is more effective within a state-wide integrated management system: the addition of storage capacity should be considered along with current and future conveyance, operation and conservation decisions and policies (Lund et al. 2014).
- Investigations for additional surface storage were conducted under the CALFED Bay-Delta Program and recently updated (http://www.water.ca.gov/storage/).
    - If constructed, the North-of-the-Delta Offstream Storage (NODOS; Sites Reservoir) project would store up to 1.8 million acre-feet and provide up to 500

thousand acre-feet per year on average of total water supply benefits (CDWR 2014a).
  - Comprehensive plans (CP) were developed to raise the height of Shasta Dam by 6.5 (CP1), 12.5 (CP2), or 18.5 feet (CP3, CP4, CP4A, and CP5) that would increase the Lake storage capacity by 265, 443, and 634 thousand acre-feet, respectively (USBR 2015a).
  - Construction of a new dam at Temperance Flat River Mile 274 in the Upper San Joaquin River would result in a reservoir with 1,260 thousand acre-feet storage capacity (USBR 2014).
- A flexible framework for assessing reservoir operations risk under climate change has been developed focusing on the CVP and SWP systems. The risk metrics selected were related to deliveries and carryover storage. Notable impacts to operation of the CVP and SWP systems included increased winter runoff, reduced spring-summer reservoir inflows, and a net annual reduction in surface water supply. Under future climate change (2041-2070) conditions: (1) reservoir operations would mitigate the effects of runoff variability on water deliveries by increasing reservoir flexibility and depleting carryover storage; (2) operational impacts, including mean annual delivery and carryover storage, would be more sensitive to change in annual precipitation than mean annual temperature change; and (3) SWP export would be affected less and have greater conveyance flexibility due to its larger capacity than the CVP system (Brekke et al. 2009).

<u>Operation of Storage Facilities</u>

Operations of storage facilities could be facilitated by adopting and providing a functional flow regime for downstream ecosystems (Grantham et al. 2014). The “natural stream flow” needed to support native species includes the volume (magnitude) of flow, direction of flow, timing of flow, frequency of specific flow conditions, duration of various flows, and the rate of change in flows with sufficient physical (e.g., temperature) and chemical qualities (e.g., dissolved oxygen, pH, conductivity, etc.). Such a functional flow regime should be designed to enhance the survival and migration of species of concern. For example, several studies have demonstrated the importance of pulse flows (or high discharge events during wet years) for the outmigration and survival of salmon in the Sacramento and San Joaquin River systems (Kiernan et al. 2012; Pyper et al. 2013; Michel et al. 2015; Sturrock et al. 2015). Such flows could also provide water to floodplain habitats that are important habitat for fish rearing and migration.

- In highly managed and modified rivers systems that support competing water uses, greater sophistication in designing and implementing flows that are optimized for multiple uses including ecosystem services and functions, water supply, hydropower generation, recharge of local aquifers, and flood control, among others, is needed. The restoration of a more natural flow regime by adding key functional flows at the most ecologically significant times of the year may be the best option available in these systems and at the present time. A functional flows approach focuses on retaining

specific process-based components of the natural hydrograph and provides the best opportunity to encompass geomorphic and ecologic processes and functions alongside varied human needs when developing flow regimes in regulated river systems. Key functional flow components include wet-season initiation flows, peak magnitude flows, recession flows, dry-season low flows, and interannual variability that occur with the proper magnitude, timing, and duration (Yarnell et al. 2015). The functionality of these flows could be enhanced by connecting the stream/river flows to morphologically diverse overbank areas (e.g., floodplain, connected wetlands, etc.) in both space and time and incorporating the appropriate sediment-transport regime (Yarnell et al. 2015). Thus, water management for human uses should consider the seasonality of natural flows.

- Operation of storage facilities to achieve the coequal goals (water supply reliability and ecosystem benefits) is needed. California contains more than 1,400 large dams (greater than 1.8 m in height and storing more than 60,000 cubic meters of water) and tens of thousands of smaller impoundments, many of them operated with little consideration for their effects on aquatic ecosystems. This situation is a dominant factor responsible for the rapid decline of the state's native fish fauna. Grantham et al. (2014) proposed a systematic, data-driven approach to screen and select dams that may require managed environmental flows to sustain freshwater biodiversity based on indicators of hydrological and ecological impairment. Of the 1,440 large California dams, 753 were identified that could be used for environmental flow implementation. Of the 753 dams, 181 dams were further identified for which improved environmental flow releases may be warranted based on hydrologic alteration and fish population impairment. There is a clear need to develop an integrated system of monitoring and reporting to better characterize the current state of aquatic ecosystems, hydrologic regimes, and anthropogenic modifications. Furthermore, such efforts must be closely linked to policy and governance processes to support effective implementation of environmental flow recommendations.
- Native fish population expansions can be facilitated by manipulating stream flows at biologically important times of the year. Naturally occurring high-discharge events during winter and spring can facilitate creation of favorable spawning and rearing conditions (e.g., elevated springtime flow), cooler water temperatures, maintenance of flow conditions over the length of the stream, and displace alien species. Pulse flows in early winter and spring were artificially provided to the lower Putah Creek to mimic the natural flow regime and promote native fish spawning as mandated by the Putah Creek Accord. After implementation of the Accord (2000-2008), the mean monthly stream flow was increased during eight months of the water year; with the greatest percentage gain occurring in the spring (47% gain in April and 63% gain in May). The mean annual flow was increased by 21% compared to previous years (1979-1999). The proportion of native fish to alien fish greatly increased in the affected reach. Only small increases in

flow were needed to achieve a result similar to those associated with naturally occurring higher discharge events (Kiernan et al. 2012).

- The success of Chinook salmon populations is strongly influenced by appropriate flows during the outmigration periods; wetter hydrologic years resulted in higher survivorship of outmigrating juveniles and a larger number of returns from the cohort.
    - In 2011 (a wet year), overall outmigration survival of acoustically tagged hatchery-origin Sacramento River late-fall run Chinook salmon smolts was two to three times higher (15.7%) than the previous four dry years (2007-2010) (2.8% - 5.9%). The overall higher survival in the high-discharge year (2011) was due mainly to increased survival and faster migration rate (36 km per day in 2011 compared to 17.5 – 23.5 km per day in other years) in the riverine reaches (upstream of Freeport; approximately 169 km above the Golden Gate Bridge) portion of the outmigration corridor, while survival in the brackish portions of the estuary did not significantly differ among the five years (Michel et al. 2015).
    - DNA markers were used to differentiate different runs of juvenile Chinook salmon collected from midwater trawls between October 2007 and June 2011 at the confluence of the Sacramento and San Joaquin rivers and entrance to San Francisco Bay near Chipps Island. Across years, DNA assignments indicated that fall run composed between 84% and 93% of the annual juvenile abundance, late-fall run composed 1.9% to 4.4%, and the Butte Creek spring run ranged between 3.9% and 9.0%. Mill-Deer Creek spring run and winter run each composed less than 3% of the total abundance in 2008, and less than 2% in subsequent years. Annual abundances were lowest for all runs in 2008, while the highest abundances were observed in 2011 (wet year) for fall and late-fall runs, and in 2010 for spring and winter runs (Pyper et al. 2013).
    - Chinook salmon that outmigrated as fry (less than 55 mm in length) and parr (between 55 and 75 mm in length), especially during a wet year (2000), represented a larger portion of returning adult spawners than did smolts (larger than 75 mm) in the Stanislaus River in the Central Valley. Hatchery and flow management practices should focus on the out-migration of diverse juvenile sizes to enhance the survival of juveniles. Recognition of the importance of hydrodynamic regime and life history diversity provides guidance to system managers (Sturrock et al. 2015).
- Targeted manipulation of abiotic variables such as water clarity, freshwater flow, and water exports could be used to influence fish abundances, but greater understanding of the interactions between abiotic variables and trophic interactions is required before scientifically robust management alternatives can be formulated in the upper San Francisco Estuary. Abundance data of four pelagic fish species (Delta smelt, longfin smelt, striped bass, and threadfin shad) in the upper San Francisco Estuary measured over 40 years (1967-2007) were coupled with changes in biotic and abiotic variables to identify the strongest variables associated with changes in fish abundance. There were

step declines in abundances of all four species in the early 2000s, with a likely common decline in 2002. Water clarity was a likely predictor of the abundance of Delta smelt, longfin smelt, and striped bass. Other abiotic variables, including position of the 2 ppt isohaline (X2) and the volume of freshwater exported from the estuary, also explained some of the variation in species' abundance (Thompson et al. 2010).

- When considering climate change, more flexible reservoir operations in Northern California could improve water supplies for human and environmental uses in dry years (Georgakakos et al 2012). Georgakakos et al. modeled two reservoir operational scenarios (traditional and flexible) for the Sacramento Valley using two climate change scenarios - a 50-year no climate change scenario and the IPCC Climate Change Scenario A1B (lower emissions scenario). The traditional scenario used water year types (wet, above normal, below normal, dry and critical) to model monthly human and environmental water demands. The traditional operational scenario also adhered to the Agreement of Coordinated Operation (ACO), which sets the proportion of additional water releases to meet environmental needs from the Oroville, Trinity, Shasta and Folsom Reservoirs during dry years. The flexible operations scenario determines the next month's releases optimizing the likelihood of satisfying delivery targets, required environmental flows, hydropower generation, reservoir depletion or spill for the next 9 months based on climate forecasts. This 9-month horizon optimization is repeated for every month. The flexible operational scenario also allows additional releases for environmental needs from all reservoirs without adhering to the ACO. The flexible operations scenario showed better performance in X2 management (36% less frequent violations) and annual water supply in the severest dry year (58% more supply) than the traditional scenario modeled under the IPCC Climate Change scenario A1B.
- Stream temperature is likely to increase as a result of climate change (Ficklin et al. 2013), and can reduce cold water habitat in California (Null et al 2013). Shasta Reservoir ran out of sufficiently cold water that could be released to the Sacramento River to manage water temperature in September 2014 contributing to the loss of 95% of the 2014 cohort of wild Sacramento River winter-run Chinook salmon (USBR 2015b).
- Research on hydrologic connectivity has increased over the past 30 years. In the San Joaquin River, higher flows are required, in addition to channel alterations, to recover flooded habitat areas of sufficient size to support native fish (Chinook salmon and splittail) (Merenlender and Matella 2012; Matella and Merenlender 2015).
- In the middle reach of the Sacramento River, good progress in the restoration of riparian habitats, birds, and other wildlife has been made, but not in the restoration of stream flows and geomorphic processes (Golet et al. 2013). To be most effective, restoration should promote river meanders and floodplain connectivity and restore components of the natural flow regime.
- With sea level rise, an increase in salinity is expected within the Delta that results in a need for more fresh water to meet Delta outflow water quality standards. This results in a concomitant loss of water available for export (Van Lienden et al. 2014).

- Conjunctive use is a useful tool to manage water scarcity. According to a state-wide hydro-economic analysis using the CALVIN model, increased conjunctive use can economically benefit all regions in California (Jenkins et al. 2004). Another study, also using the CALIVN model, showed that the cost of prohibitive groundwater overdraft in the Tulare Basin is not catastrophic when currently available conjunctive use infrastructure is fully utilized (Harou and Lund 2008).

Summary

The magnitude and timing of stream flows will change in the future according to multiple climate change scenarios in the Sacramento-San Joaquin river systems as a result of altered precipitation and snowmelt patterns (Pierce and Cayan 2013; Van Lienden et al. 2014; PPIC 2015). The quantity of available water for management (water yield from the watershed) might also decline due to the higher evaporation and transpiration rates under a warming climate (Berghuij et al. 2014; Goulden and Bales. 2014) and the water content in the mountain snowpack could be substantially reduced. Expanded capacity and operational flexibility of water storage facilities would be needed so that they can capture surface water flows of differing magnitudes (e.g., larger peaks during snowmelt) and periods (e.g., earlier snowmelt) in the future.

Though groundwater has been used to supplement surface water supplies, especially in the San Joaquin Valley, severe overdraft in the region during the recent prolonged drought has drastically reduced groundwater levels and storage capacity (Medellín-Azuara et al. 2015; Weiler 2014; Farr et al 2015; Howitt et al. 2015).

Operation of surface water storage should consider all beneficial uses including environmental. Water releases that mimic a more natural flow regime could have significant ecosystem benefits while using only a relatively small proportion of available water (Kiernan et al. 2012; Pyper et al. 2013; Michel et al. 2015; Sturrock et al. 2015; Yarnell et al. 2015).

CONVEYANCE

Summary of the 2013 Delta Plan

Existing configurations of Delta water conveyance and associated facilities are not sufficient to reliably meet current and projected demands for SWP and CVP exports. Exports from the Delta have been rising over the past four decades and both have reached record exports in recent years (Delta Plan, Figure 3-5). However, many factors threaten the ability to continue pumping water through the two projects at current export levels. Subsidence of the Delta islands, rising sea level, and earthquakes threaten the physical integrity of the Delta ecosystem and the levees that protect the quality of water exported. The location of the CVP and SWP pumping stations (the south Delta), along with the fact that most of the water enters the Delta from the Sacramento River, when operating, frequently cause a net “flow reversal” in the central and south Delta channels. Such reverse flows affect fish movement, including migration through the Delta, and often results in species that are free-floating or have weak swimming capability

(including young smelt or salmon) being drawn into the pumping facilities, resulting in "entrainment". Some of the entrained fish are "salvaged" (caught in facilities at the pumps, trucked, and then released to an area beyond the influence of the pumps). This process is intended to decrease the mortality of entrained fish. However, many fish, including the Delta Smelt, do not survive the collection, handling, transport, and release.

Water quality is also an issue. A portion of the river water flowing into the Delta is specifically allocated to Delta outflow to maintain low salinity water near the western edge of the Delta. Thus, water that might otherwise be used for exports must be released from upstream reservoirs to help control salinity.

Improved conveyance, by moving or modifying diversion points of the CVP and SWP as suggested in the Bay Delta Conservation Plan (BDCP), could facilitate moving water at times and from locations that are less harmful/provide the most benefits to the ecosystem and other beneficial uses. At the time (2013) of the adoption of the Delta Plan, conveyance improvements were being evaluated as part of BDCP. BDCP was developed to create a more natural flow pattern in the Delta and enable water exports when hydrologic conditions result in the availability of sufficient water, consistent with State and federal requirements, the terms of conditions of SWP and CVP water delivery contracts, and other existing applicable agreements. Even if a decision to build the BDCP is made, local water management actions would still be needed over the next 15 years until the BDCP starts operating. Improvements in the Delta levee system are needed immediately to protect the existing in-Delta conveyance.

<u>Update (2015)</u>

Land subsidence in Delta islands along with the influence of climate change (e.g., frequency of intense storms and sea-level rise) are projected to impact through-Delta conveyance due to increased frequency of flooding, overtopping of levees, and increased hydraulic pressure against the levee system. In addition, there is always a chance of major earthquakes in the region that could damage the Delta levee system and water conveyance infrastructure. The infrastructure south of the Delta that conveys water to the Central Valley and southern California will require continuous monitoring and maintenance due to land subsidence that results from the severe overdraft of groundwater in the region.

- Sea level rise will ultimately increase salinity above appropriate concentrations for drinking and irrigation in some areas of the western Delta if freshwater outflows are not increased. The through-Delta conveyance system is very likely to experience salinity increases (Fleenor and Bombardelli 2013).
- At the Golden Gate Bridge in San Francisco, sea level is projected to rise by 42 – 166 cm (mean 92 cm) by the end of the 21st century, relative to 2000 levels (Van Lienden et al. 2014). Higher sea levels could impact the Delta in two ways: salinity intrusion (water quality) and enhanced flooding potential.
- Using an updated estimated mean sea level rise of 92 cm, it is projected that salinity could increase 18-23% (at Emmaton and Jersey Point, respectively) in the early 21st

century (2012-2040) and 65-88% by the end of the century (Van Lienden et al. 2014). The impacts of salinity changes in the Delta and their effects on water supply reliability, based on the revised long-term sea level rise projections, is a very active area of scientific research.

- For California's water supply, the largest effect of sea level rise would likely be in the Sacramento-San Joaquin Delta. Increased intrusion of salt water from the ocean into the Delta could require increased releases of freshwater from upstream reservoirs or reduced pumping from the Delta to maintain compliance with current Delta water quality standards (Anderson et al. 2008). Water supply facilities that are located close to the ocean, such as the Contra Costa Water District intake in Old River at Rock Slough, are more likely to be affected by climate change and sea level rise. Based on a projected 30 cm rise in sea level by the mid-21st century and without any changes to system operations, it is projected that the amount of time that the SWP and CVP could operate would be reduced based on water quality criteria (i.e., chloride concentration) by up to 10% at this location (Anderson et al. 2008).
- Subsidence and sea level rise in combination would increase anthropogenic accommodation space (Accommodation Space Index: space below mean sea level not filled with sediment or water) in the Delta. These factors also lead to a regional increase in the forces that cause levee failure. The Levee Force Index, a proxy for the cumulative forces acting on levees, is projected to increase significantly in the future. These forces produce regional increases in the potential for island flooding. Based on continuing increases in the Levee Force Index and the Accommodation Space Index and limited support for Delta levee upgrades, there will be a tendency for increases in and impacts of island flooding with subsequent costs for repairs (Mount and Twiss 2005).
- A 62% probability (37% to 87% confidence bounds) of a major (M≥6.7: moment magnitude greater than 6.7), damaging earthquake striking the greater San Francisco Bay Region over the period of 2002-2031, most likely occurring along the seven main fault systems, was estimated. More specifically, the probability for M≥6.7 earthquakes occurring east of San Francisco Bay was estimated to be 46%, while one occurring west of San Francisco Bay had an estimated probability of 32% for the same period. The easternmost faults along the Interstate 68 corridor in central and eastern Contra Costa and Alameda Counties have a mean combined estimated probability of 19% for M≥6.7 earthquakes. The estimated probability goes up to at least 80% for a moderate earthquake (M>6.0) (Working Group on California Earthquake Probabilities 2003).
- Hydrodynamic simulations show that exports through the Delta resulted in reverse flow conditions in the Old and Middle rivers more than 91% of the time from 1986-2005 when compared to the unimpaired flow conditions from 1925-2000 (Fleenor et al. 2010). Through-Delta exports appear to reduce the salinity of water in the central and southern Delta, but consequently expand the regions of the Delta where salinity progressively increases upstream toward the San Joaquin River, contrary to natural conditions and

potentially confusing migrating fish. Much larger San Joaquin River flows would be needed to eliminate this adverse water quality gradient. Flow prescriptions for the future will need to be able to respond to further changes in the Delta's biological composition due to additional invasive species, continuing changes in sea level and climate, as well as the permanent inundation of many Delta islands and the intentional development of marshland and floodplain habitat (Fleenor et al. 2010).

- Delta islands, depending on location, could impact salinity levels when they are flooded. The permanent flooding scenarios of eastern and southern islands showed little long-term salinity impacts at all examined locations in the Delta. Those of the western five islands (Sherman, Twitchell, Bradford, Brannan-Andrus, and Jersey Islands) and other 20 islands showed significant increases in conductivity (indirect measurement of salinity) in the southwestern and southern Delta including at the locations of the pumping plants (Fleenor et al. 2008).
- Delta peripheral exports could either increase or decrease salinity depending on location. Dual conveyance is projected to decrease the salinity of exported water, but additional flow releases may be required to meet agricultural salinity standards in the Delta along the Sacramento River. Some in-Delta agricultural water users, especially along the Sacramento River, may encounter more frequent salinity issues if dual conveyance is introduced while the southern Delta may experience the opposite outcome (Fleenor and Bombardelli 2013).
- Land subsidence has caused damage to canals, reduced canal's conveyance capacity, and required millions of dollars for repairs in California (Sneed et al 2013), and it continues in many areas of the Central Valley. Between Huron and Kettleman City, more than 8 inches, with a maximum of 13 inches, of subsidence was observed along a 1.3 mile stretch of the California Aqueduct from July 2013 to March 2015 (Farr et al. 2015). Approximately 6 inches of subsidence was observed from December 2010 to May 2014 in Yolo in the same study (Farr et al. 2015). Based on the recent groundwater level decline rates, the southern San Joaquin and western Sacramento valleys are exposed to higher potentials of future subsidence (CDWR 2014b).

<u>Summary</u>

Water conveyance through the Delta will be subjected to various destabilizing factors in the future in addition to the existing environmental concerns (e.g., reverse flows in the Middle and Old Rivers, salinity intrusion, unnatural flow regimes, etc.). Sea level rise and more frequent and intense storms under various climate change scenarios along with continuing subsidence in Delta islands would enhance the risk of levee failure. The constant threat of a major earthquake that might result in multiple failures of Delta levee systems enhances the overall risk. These factors could further degrade water quality in the Delta impacting the Delta ecosystem and water exports. In addition, increasing salinity due to higher sea levels would require more freshwater flows through the Delta to maintain the water quality in the south Delta where the current major water diversion facilities are located.

Water delivery systems south of the Delta already have been subjected to severe land subsidence due to prolonged groundwater overdraft. Continuous monitoring and maintenance of the canal system would be needed to maintain the integrity and reliability of the current water delivery system to the south Central Valley and southern California.

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