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RESEARCH

21st Century California Water Storage Strategies

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ABSTRACT

The goal of this paper is to analyze water storage projects constructed and planned in California since 1980, in contrast with storage constructed before that date. As a result of California's highly variable climate, storage is an essential tool for agricultural and urban water users. Today, the state regulates approximately 1,250 reservoirs, with a combined storage of 42 million acre-feet. Federal agencies regulate approximately 200 additional reservoirs. The vast majority of this surface storage was constructed before 1978, when New Melones Dam, the last large on-stream water supply reservoir in California, was completed. The role of storage in meeting future needs remains a high-profile issue in the California water debate. For example, funding for new storage was the largest item in Proposition 1, the most recent water bond voters approved. This analysis included a review of existing literature, such as the California Department of Water Resources Division of Dam Safety database, California Water Commission documents about new storage proposals, water agency documents, and interviews with water agency staff and others. Water managers face dramatically different conditions today, in comparison to conditions before 1980. These conditions have led to new approaches to water storage that represent a dramatic departure from past storage projects. During the past 37 years, a wide range of new water storage strategies have been planned and implemented. These facilities have created a combined new storage capacity greater than that of Lake Shasta, California's largest reservoir. These new storage strategies suggest the need to revisit the fundamental definition of water storage. With limited potential for new storage drawing from the state's rivers, California must choose storage projects wisely. By learning from successful strategies in recent decades, decision-makers can make better storage investment decisions to help reverse declines in ecosystem health and improve water supply reliability.

KEY WORDS

21st century, water storage, water policy, California water policy, water storage, dams, groundwater storage, environmental benefits, reservoirs.

INTRODUCTION

Artificial water storage is an important part of nearly all of the dozens of significant water systems in California. Since statehood, tens of billions of dollars have been invested in more than 1,400 dams across the state. In the coming decades, tens of billions of additional dollars will be invested in California to ensure adequate water supplies. One of the important questions water managers must answer in making these investments is the extent and type of water storage best suited for future conditions.

This paper explores the history of water storage development in California through three phases, beginning before the construction of Hetch Hetchy Reservoir, the first large multi-purpose reservoir in the state, through the golden age of dam building from 1923 to 1978, and finally, storage projects planned and constructed since 1980.

Storage-related policies and future investments in water storage can be informed by the successful storage innovations and investments of the past 4 decades. In addition, many past water storage projects have resulted in significant damage to aquatic ecosystems, wildlife, and fisheries. An analysis of recent storage projects can reveal opportunities to avoid further damage, and even to provide significant environmental benefits.

METHODS

This analysis included a review of existing literature on storage projects in California, including relevant recent articles, the California Department of Water Resources (CDWR) Division of Safety of Dams (DSD) database, other CDWR documents, California Water Commission documents on new storage proposals (including the Commission's March 2015 scoping survey), and water agency documents. Interviews with water managers also provided detail on water storage projects that are in the planning process.

RESULTS

Water Storage in California — Moving Water Over Space and Time

Water is stored in many ways in the natural world—in snowpack, glaciers, groundwater, wetlands, lakes, and soil moisture. Artificial water storage is defined as projects that provide the ability to control, retain, and help move that water from places and times of abundance to places and times of need. Artificial storage includes reservoirs, active groundwater storage, managed floodplains, stock ponds, tanks, and cisterns. Water may be stored over long periods or be held for only hours or days, as in the case of transient floodplain storage.

Storage has been a major component of water management in California since Native Americans constructed storage facilities at Spanish missions over 2 centuries ago (SBBG [date unknown]). One major reason for the importance of storage is that the California waterscape is a land of extremes. These extremes in California's climate can be measured in both spatial and temporal terms, including seasonal variability, inter-annual variability, and geographic variability.

Seasonal Variability

California's Mediterranean climate delivers the vast majority of annual precipitation during half of the year: from October to April (NCDC [date unknown]). In most of the state, the remainder of the year is extraordinarily dry. This dry season also corresponds with peak agricultural and urban water demands.

Inter-Annual Variability

Precipitation in California varies dramatically from year to year. Climatologists have found that California has one of the most variable climates in the world (Dettinger et al. 2011). Recent years provide a clear example, with a wet 2011, followed by 4 severe drought years; a 2016 that was just above average; and a wet 2017. Droughts of 4 years or more have occurred five times in the 20th century.

Paleoclimate analysis reveals that dramatic inter-annual variations have affected California for millennia. Reconstructed climate records show that during the period from the 1400s to the late 1500s, California experienced four drought cycles of 10 years or longer (CDWR 2015a).

Geographic Variability

Extreme differences in precipitation also occur among different regions of the state. Temperate rainforest conditions occur on the north coast, while extraordinarily dry desert occurs in the state's southeast. This geographic variability can be measured in several ways. Seventy-five percent of the state's water demand is in the south, while 70% of the state's precipitation is in the north. Two-thirds of the state's runoff is from one-fifth of the state's landmass, while the driest one-third of the state contributes just 0.1% of runoff. In the south coast and the Tulare Lake Basin, average water use is twice the amount of water locally available (CDWR 2003a).

As a result of this remarkable variability, providing water supplies flexibly and reliably over time and space has always been a major driver of storage projects in California.

Existing Surface Storage Capacity

Today, California has a large amount of managed water storage, largely in the form of artificial surface storage, particularly on-stream reservoirs. California also has some of the largest and most complex water projects in the nation. For example, the State Water Project (SWP) and the federal Central Valley Project (CVP) include 33 and 20 surface storage reservoirs, respectively. Total SWP storage is 5.8 million acre-feet (maf) and CVP storage totals 9 maf. In total, California has 1,250 reservoirs regulated by the CDWR's DSD, with a total capacity of 42 maf (CDWR–DSD 2015); 41 maf of this total is held in nearly 200 storage facilities with a capacity greater than 10,000 af (CDWR 2013a). According to Lund et al. (2014), nearly all of California's surface storage capacity was constructed before 1978. This pattern is also true nationwide (Graff 1999).

Although total reservoir storage capacity in California is 42 maf, far less than this amount is used as active storage in any given year. On average, excluding snowpack, 8 to 14 maf of water is stored in California during the wet season for dry-season use. As Figure 1 shows, 5 to 8 maf of this amount is stored in reservoirs and the remaining 3 to 6 maf in groundwater. Combined, this annual active storage quantity represents 23% to 41% of average net agricultural and urban use of approximately 34 maf per year (Lund 2011). Together, this average annual active groundwater and surface storage is roughly comparable with average annual Sierra Nevada snowpack of 15 maf.

EARLY WATER STORAGE: PRE–1923

Since the first water storage projects were built to serve Spanish missions, water storage projects built in California have changed in type and scale. Before 1923, most storage facilities were relatively small. An analysis of data from the CDWR's DSD found that 199 existing state-regulated dams constructed before 1923 have a combined storage capacity of 2.1 million af (CDWR–DSD 2015). This represents just 5% of the state's current total reservoir storage capacity. Only two state-regulated facilities built before 1923 hold more than 100,000 af. The largest of these, Cache Creek Dam, expanded Clear Lake by 315 maf. It is important to note that the DSD list excludes federal facilities, including a few large older storage projects such as Lake Tahoe Dam, completed in 1913, with a capacity of 732,000 (Associated Press 2013). This dam would bring total pre-1923 storage to 2.8 million af.

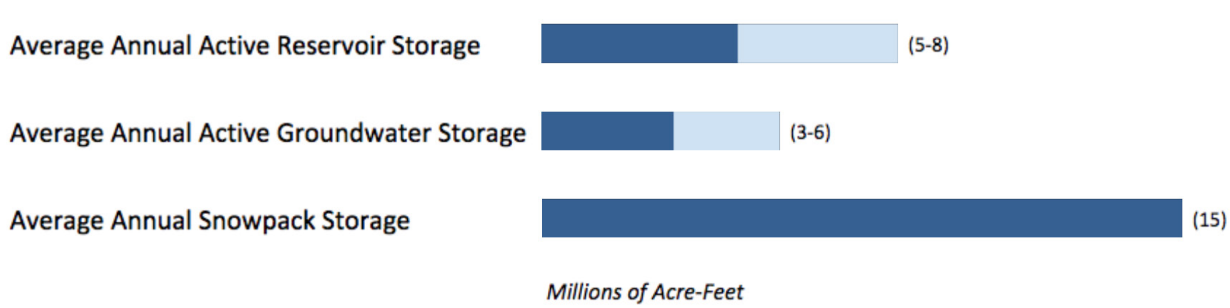

Figure 1 Comparison of average annual active reservoir and groundwater storage and average annual Sierra Nevada snowpack

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THE ERA OF DAMS: 1923–1978

The first large modern storage project built in California was O'Shaughnessey Dam, which was completed in 1923 (Lund et al. 2014). For the next 55 years, until 1978, when New Melones Reservoir was completed, a large number of surface storage projects were built in California, including approximately 800 dams regulated by the state's DSD. That represents a pace of more than 14 new storage facilities completed per year—or more than one new dam per month for more than half a century.

After 1923, there was a pronounced focus on increasingly larger facilities. This trend continued until the 1940s, when construction of the state's largest reservoirs began. Today, the largest 10% of the state's reservoirs have 95% of total surface storage capacity. The largest 14 reservoirs—1% of the state's total—hold 25.6 million af, or 60% of the state's total surface storage capacity (Lund et al. 2014). Table 1 shows the capacity and other characteristics of these 14 facilities. All but two of California's largest surface storage facilities were completed between 1923 and 1978—and those are the two smallest facilities on this list of largest reservoirs of California (Table 1).

Characteristics of Traditional Storage Projects

There are many similarities among the traditional storage projects constructed before 1978.

On-Stream Dams

Twelve of the 14 dams summarized below are on-stream facilities. Significantly, the off-stream Diamond Valley project was the last of these facilities to be constructed.

Distance from End Users

Comparing the period before 1923 to the period between 1923 and 1978, as the size of storage facilities grew over time and as promising reservoir sites near demand centers became increasingly scarce, storage facilities were built farther and farther from demand centers. For example, the six CVP and SWP

Table 1 The 14 largest surface storage facilities in California

#	Name	Capacity (af)	Owner	Completed	Type[a]	Stream
1	Shasta Lake	4,552,000	USBR	1945	on-stream	Sacramento River
2	Lake Oroville	3,537,577	DWR	1968	on-stream	Feather River
3	Trinity Lake	2,448,000	USBR	1961	on-stream	Trinity River
4	New Melones Lake	2,400,000	USBR	1978	on-stream	Stanislaus River
5	San Luis Reservoir	2,041,000	USBR and DWR (joint facility)	1967	off-stream	
6	Don Pedro Reservoir	2,030,000	Modesto Irrigation District and Tuolumne Irrigation District (joint facility)	1971	on-stream	Tuolumne River
7	Lake Berryessa	1,602,000	Solano Irrigation District	1958	on-stream	Putah Creek
8	Lake Almanor	1,308,000	PG&E	1927	on-stream	North Feather River
9	Folsom Lake	1,120,200	USBR	1955	on-stream	American River
10	Lake McClure	1,024,600	Modesto Irrigation District	1926–1967	on-stream	Merced River
11	Pine Flat Lake	1,000,000	USACE	1954	on-stream	Kings River
12	New Bullards Bar Reservoir	996,103	Yuba County Water Agency	1970	on-stream	North Yuba River
13	Diamond Valley Lake	810,000	Metropolitan Water District of Southern California	1999	off-stream	
14	Lake Tahoe Dam	732,000	USBR	1913	on-stream	Truckee River

a. As a result of the definition used by CDWR's DDS, DDS considers many dams to be "on-stream" dams that are frequently described as "off-stream" facilities, including Los Vaqueros and Diamond Valley. This table uses the common public definition, not the DDS definition.

storage facilities in Table 1 are located far from the largest demand centers for those projects. This trend is discussed in greater detail in Appendix B.

Focus on Average Yield

Project operations for traditional surface storage frequently focused on delivering average firm yield. In practice, this meant maximizing average deliveries, rather than prioritizing holding water to prevent shortages during extended dry periods. For example, in the middle of the 1987–1992 drought, the U.S. Bureau of Reclamation proposed to drain Lake Shasta, the largest reservoir in the state, to dead storage. The drought continued for another several years. Had Reclamation's proposal been implemented, its proposed loss of storage would have seriously affected Sacramento River salmon and CVP water users. This focus on average yield lowers the unit cost of water and increases hydropower revenue, but increases the risk of dry-year shortages.

Supply-, Hydropower-, and Flood-Control-Focused Planning

Planning for storage projects has traditionally focused narrowly on water supply, hydropower, and flood control. As discussed below, ecosystem health traditionally received little focus during project planning. This narrow approach to storage often ignored more integrated storage solutions, such as the potential role of floodplain restoration projects, and the expansion of downstream flood-conveyance capacity to allow the re-operation of storage facilities. Another implication of the traditional storage approach is reduced natural groundwater recharge during periods of high flows. Although it is important to note that some of that stored water is used to irrigate agricultural lands, allowing some artificial groundwater recharge. Finally, the traditional supply-oriented planning approach frequently downplayed distributed and demand-oriented water-management options and alternative water sources, such as water-use efficiency, water recycling, urban stormwater capture, etc.

Environmental Damage

In some cases, anticipated ecosystem benefits were included in cost allocation and project purposes during the period from 1923 to 1978. However, actual benefits have frequently failed to materialize (Collier et al 1997). For example, Friant and Trinity dams were justified in part on the basis of anticipated environmental benefits, including maintaining the Trinity River fishery and improving the ability to manage salinity in the Delta. In actuality, for decades after construction, these promised benefits did not play a significant role in shaping the operations of these two facilities. Thus, rather than providing ecosystem benefits, these projects seriously affected the San Joaquin and Trinity rivers. In a global analysis, the World Commission on Dams concluded that large dams generally have extensive effects on rivers, watersheds and aquatic ecosystems (World Commission on Dams 2000).

CHANGED CONDITIONS TODAY

Today, water managers face dramatically different conditions from those managers faced from 1923 to 1978. Contemporary changes that lead to unprecedented and growing statewide challenges include limited new water for traditional storage, growing signs of environmental damage from storage projects, anticipated effects from climate change, and changing public attitudes.

Limited Availability of New Water

Significant evidence suggests that there is limited new water available for diversion or capture by new traditional storage projects.

Over-Allocation of Water Rights

Grantham et al. (2014) found that the state of California has issued water rights for 370 maf, while mean annual runoff is approximately 70 maf. Thus, all current water rights represent an amount five times the average statewide runoff. In some watersheds, water rights exceed the river's average annual flow by eight-fold.

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Few Remaining Free-Flowing Rivers

California has few remaining free-flowing rivers. In the Central Valley, the largest streams without a major dam include the Cosumnes River and Cottonwood Creek. In addition, where rivers are protected as Wild and Scenic Rivers, this designation often comes with no, or minor, supply effect on water users. For example, the water that flows down many of the state's Wild and Scenic Rivers (e.g., the Tuolumne, Merced, American, Feather, Kern, Kings, and Owens) is subsequently diverted or stored by downstream facilities. Several other Wild and Scenic Rivers are physically isolated from the state's major water systems and demand centers (e.g., the Amargosa, Eel, Smith, Klamath, Big Sur, and Black Butte rivers).

Declining Ecosystem Health

The extensive damage that existing water development has caused creates new obstacles for proposed traditional storage projects. Moyle et al (2010) reviewed the status of the state's 129 native fish species and found that seven (5%) of California's native fish species are extinct. Thirty four (26%) are listed or qualify for listing under the ESA. Another 32 (25%) are considered imperiled, qualifying as California Species of Special Concern with potential for future listings. Only 22 species (17%) were found to be relatively secure. At the time of this writing, CDFW (2017) reported that thirty-four California fish ESUs were listed under the federal and state ESAs.

These declines have caused economic effects as well. In 2008–2009, because of precipitous declines in salmon populations, California's formerly abundant salmon fishery was closed for the first time in state history, at a cost of more than twenty thousand jobs (Southwick Associates 2012).

Although there are multiple causes for ecosystem decline in California rivers, in the Bay–Delta, water development is widely seen by scientists as a central driver (Hanak et al. 2013). The State Water Resources Control Board (SWRCB) and the State of San Francisco Bay report have also concluded that the Bay–Delta is highly impaired by water diversions (Crader et al. 2010; SFEP 2015; SWRCB 2016).

Beyond the Bay–Delta, many other aquatic ecosystems—including the Klamath, Trinity, Russian, Salinas, Carmel and Santa Ana rivers—have also been severely affected by water development. These ecosystem declines are increasingly affecting the operation and reliability of California water systems.

Anticipated Climate Change Effects

Climate scientists anticipate that climate change will significantly affect water resources and existing water supplies (EPA and CDWR 2011; Pierce 2012; Kadir at al. 2013; CDWR 2015b). Those anticipated effects include the following:

- Rising air temperatures that may increase evaporation and increase water temperatures in streams and rivers
- Greater variation in precipitation, including more severe and longer droughts
- A greater percentage of precipitation falling as rain, instead of snow
- Decreased snowpack
- A shift in peak runoff to earlier in the year
- A risk of reduction in total precipitation, particularly in the southern part of the state

These effects, which will interact in uncertain and complex ways, add additional challenges for water managers who are already facing the difficulty of working with complex and damaged aquatic ecosystems.

Alternative Sources of Water

In recent years, water managers have realized that non-traditional sources provide significant potential water supplies that previously were either less available, less cost-competitive, or simply less in the mainstream of water-management discussions. These sources include urban and agricultural water efficiency, water recycling, cleaning up contaminated groundwater, and capturing urban stormwater.

The emergence of alternative supplies is reflected in many places. For example, the SWRCB has adopted a policy to develop an additional 1 maf of recycled water by 2020 (in comparison with 2002) and 2 maf by 2030. The SWRCB has also adopted a policy calling for the development of an additional 1 maf of urban stormwater by 2030 (SWRCB [date unknown]). As shown in Figure 3, together these goals represent more water than the 2.55 maf average annual delivery capacity of the SWP (CDWR 2015c). The City of Los Angeles has adopted an integrated regional water plan that would reduce the purchase of imported water by 50% by 2024 (City of Los Angeles 2014). And, finally, Orange County has emerged as a world leader in water recycling.

Changing Public Attitudes

Water managers have long been concerned about public acceptance of recycled water as a domestic supply source. That concern is captured in San Diego's difficult experience a decade ago. However, the drought, along with several other factors, has increased public acceptance of recycled water to 73% (Probe Research, Inc. 2015). Thus, in addition to the availability of new water sources, the public's acceptance of those sources has changed as well.

Taken together, these changed conditions are dramatically different from those water managers faced before 1980. This increase in uncertainty and alternative choices presents significant challenges and opportunities for both water managers and the environment. Not surprisingly, these changes have profoundly shaped how water managers approach storage since 1980.

EMERGING STORAGE STRATEGIES SINCE 1980

As discussed above, the era dominated by traditional large, on-stream, water-supply dam construction

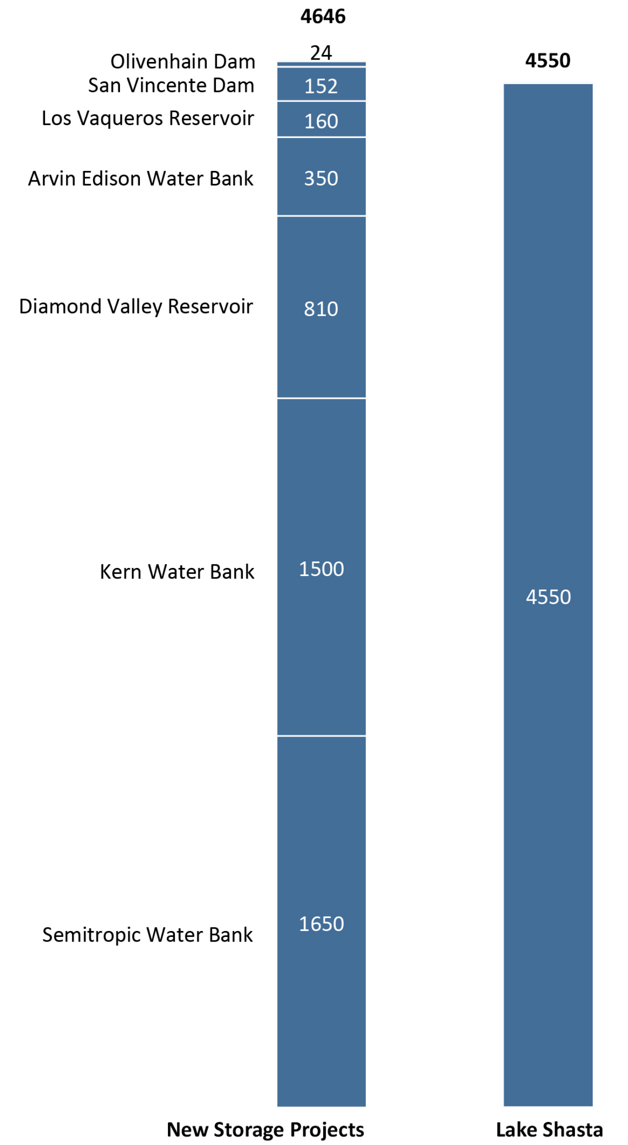

Figure 2 The capacity of major new storage projects since 1990 in comparison with Lake Shasta

Table 2 Large storage projects constructed in California since 1980

Name	Capacity (af)	Owner	Date of completion	Project type
Semitropic Water Bank	1,650,000	Semitropic Water Storage District	early 1990s	groundwater
Kern Water Bank	1,500,000	Kern County Water Agency, Kern Water Bank and the City of Bakersfield	2000–2004	---
Diamond Valley Reservoir	810,000	Metropolitan Water District of Southern California	1999	off-stream
Arvin Edison Water Bank	350,000	Arvin-Edison Water Storage District	1995	groundwater
Los Vaqueros Reservoir	160,000	Contra Costa Water District	2012	off-stream
San Vincente Dam	152,000	San Diego County Water Authority	2014	off-stream
Olivehain Dam	24,000	San Diego County Water Authority	2013	off-stream

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in California ended in the late 1970s. Since then, water managers have designed and constructed non-traditional storage projects with a wide range of different characteristics. These new storage strategies can be grouped into several categories. In addition, a small number of traditional storage projects have been proposed in recent years.

Together, storage investments in the past 4 decades represent a significant amount of new storage. For example, eight significant storage projects built in California since 1990 (Figure 2; Table 2) represent a total new storage capacity greater than that of Shasta Dam, the state's largest reservoir, or more than a dozen times the capacity of San Francisco's Hetch Hetchy Reservoir. More important, all of these are groundwater and off-stream surface storage projects—a dramatic departure from the years before 1980.

Today, there are a few proposals for new large traditional surface storage projects (e.g., Sites Reservoir, Temperance Flat Reservoir, and the proposed Shasta Dam raise).

Nevertheless, the trend toward new storage approaches since 1980 is significant. It reflects the emergence of integrated water management as a foundational water-management strategy, in that many of recently constructed and planned projects incorporate more than one non-traditional approach to storage. These new storage trends can be summarized as follows. (See Appendix A for more detail on the categories and projects below).

New Infrastructure Approaches to Expanding and Accessing Storage Capacity

Water managers have developed a broad range of new infrastructure strategies to create and expand access to storage capacity, including the following:

- Groundwater storage and banking (e.g., Kern Water Bank).
- Large off-stream storage facilities (e.g., Diamond Valley).
- Decentralized off-stream storage (e.g., north coast storage facilities designed to improve conditions for Coho Salmon).
- Distributed storage designed to improve water quality (e.g., targeted groundwater recharge to improve water quality for Central Valley communities that suffer from contaminated groundwater sources).
- Conveyance projects that improve storage benefits (e.g., the proposed intertie between Nacimiento Reservoir and San Antonio Reservoir in the Salinas River watershed).

Improved Management to Provide Storage Benefits

The previous category includes new infrastructure investments. However, innovative management can also provide storage benefits without the construction of new physical storage capacity. This broad category includes the following:

- The re-operation of existing reservoirs to better balance flood management and water supply operations (e.g., Sonoma County Water Agency's proposal for the Russian River watershed).
- The restoration of wet meadows (e.g., in the Feather River watershed).
- Forest management to provide downstream storage benefits.
- Floodplain restoration, including groundwater recharge and/or the re-operation of upstream storage facilities.
- Conjunctive use of groundwater and existing surface storage facilities.
- Groundwater clean-up and storage (e.g., Los Angeles Department of Water and Power's proposals in the San Fernando Valley).
- On-farm retention, to increase groundwater recharge.

New Water Sources/Reducing Reliance on the Delta

Before 1980, water storage projects in California relied nearly exclusively on water from rivers and natural aquatic systems to provide water for storage. However, in recent years, a growing number of projects have been planned or constructed that rely on non-traditional water sources, such as recycled

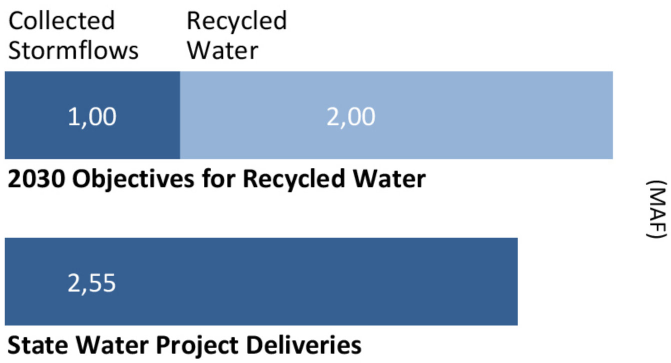

Figure 3 SWRCB recycled and stormwater goals and average SWP deliveries

water or urban stormwater. These non-traditional sources represent a major new source of water available for storage. These sources also offer the potential to reduce reliance on the Delta, as required by the Delta Reform Act, and to develop supplies that are more resistant to the effects of climate change. These new sources also represent a significant amount of new water. For example, the SWRCB has adopted 2030 goals for the development of recycled water and urban stormwater that, together, represent more potential new water supply than current average deliveries of the SWP (Figure 3).

Another comparison demonstrates the scale of potential water recycling in southern California. The average annual discharge of treated wastewater by the Hyperion Treatment Plant, the largest in southern California, is 294,000 af (LADWP 2015). This is equal to 91% of the 322,000 af average annual flow of the Santa Ana River, the largest river in southern California (Warner et al. 1984; Figure 4).

Indirect reuse recycling projects have not traditionally been seen as storage projects. However, as in the case of traditional storage projects, they frequently involve placing water in a storage facility (usually groundwater), storing that water for a significant period, and managing that stored water differently in wet and dry periods. In these ways, indirect reuse projects can be considered as storage projects. Agency plans suggest that the role of recycling as a source of water for storage is likely to increase in the future.

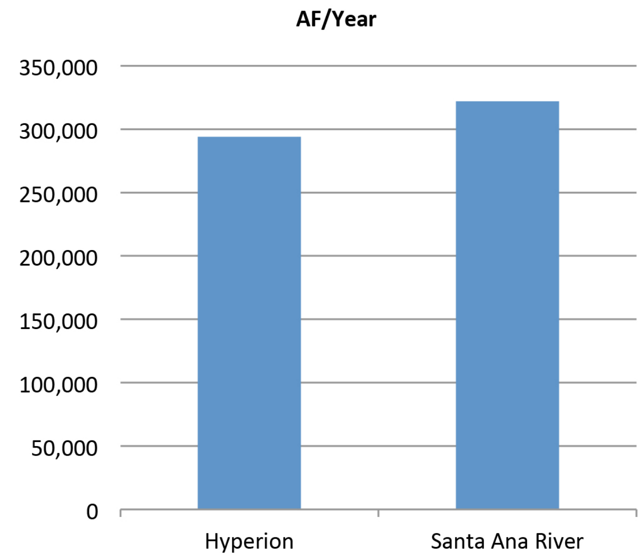

Figure 4 Annual discharge of the Hyperion Treatment Plant and annual flow of the Santa Ana River

Dry-Year Supply Focus

Before 1980, the water supply metric used to evaluate many proposed storage projects was firm average long-term yield. However, for projects constructed in the past 15 years, dry-year reliability has emerged as a new priority metric. This is also true for many projects currently being planned.

After the 1987–1992 drought, many water agencies concluded that storage investments were needed to improve dry-year supply reliability. For example, dry-year reliability was a significant driver in the construction of the following storage projects built since 1990:

- Diamond Valley Reservoir
- Expanded Los Vaqueros Reservoir
- Kern Water Bank
- Arvin–Edison Water Bank
- Semitropic Water Bank
- Olivenhain Dam
- San Vicente Dam expansion

The difference between managing for average yield and for dry-year supply is significant. Projects that focus on dry-year benefits, particularly in urban

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areas, produce significant economic benefits, because the value of avoiding severe urban water shortages can be high. On the other hand, water projects managed for average yield may provide few dry-year benefits, particularly during multiple dry years. In addition, water from projects focused on average yield can be used to bring new permanent crops into production. Permanent crops cannot be fallowed and, therefore, require a reliable dry-year supply. As a result, if projects managed for average yield are used to irrigate more permanent crops, they could actually increase dry-year shortages and increase pressure on groundwater aquifers. Thus, the economic benefits of a new storage project managed for average agricultural yield could be modest, whereas the economic benefits of a new project managed for urban dry-year supply could be significant.

Distributed Storage

Many recent and proposed projects are smaller and located closer to end users than traditional storage projects, which, as discussed above, are often centralized, large, and sited far from end users. This analysis suggests that the recent distributed approach to storage offers several benefits, as described below.

Regional Conditions and Needs

A distributed approach allows storage solutions and operations that are tailored specifically to regional and local needs (e.g., to take advantage of non-traditional water sources).

Local Control

A distributed approach to storage provides greater regional control. For example, a water manager may have greater control over water stored for dry conditions in a local facility than in a large SWP or CVP facility that many users share.

Reduced Regulatory Uncertainty

Regulatory requirements (e.g., Delta outflow and ESA biological opinions) affecting large traditional surface storage projects can affect their ability to provide water supply benefits. Water managers believe that new distributed storage projects are subject to less regulatory uncertainty.

Reduced Vulnerability to Disruption

Locating water closer to end users can reduce risk in multiple ways, including reduced disruption as a result of earthquakes, levee failures, and other risks.

Ecosystem Benefits

Traditional storage projects have frequently promised environmental benefits. However, as discussed above, their record of delivering these benefits is poor. Several new strategies appear to offer more tangible environmental benefits. These benefits fall into two categories, as discussed below.

Direct Benefits

In recent years, storage projects have included retrofits to provide improved environmental performance (e.g., the Shasta Temperature-Control Device). In addition, a new category of storage-related projects has become far more prominent: the removal of antiquated storage facilities to provide environmental benefits, particularly improved fish passage (e.g., decommissioning San Clemente Dam on the Carmel River) (CDWR 2009). If funded by the CWC, the proposed expansion of Los Vaqueros Reservoir in Eastern Contra costa County would devote a significant portion of its yield to drought prone South of Delta wetlands, providing critical waterfowl and wildlife habitat. This would be the largest contribution of Central Valley wetland water since Congress mandated improved supplies in 1992 (CCWD 2017). Additional new storage strategies are also designed to benefit fish and wildlife. River Partners has sought funding from the California Water Commission for a floodplain restoration project to provide significant ecosystem benefits as well as groundwater recharge and conjunctive-use storage benefits. Recent distributed storage projects on coastal Coho Salmon streams also provide clear environmental benefits. Thus, some new storage projects provide direct, tangible environmental benefits (River Partners 2016).

Indirect Benefits

The emergence of new storage projects that reduce reliance on the Bay–Delta and other aquatic ecosystems presents the opportunity to provide indirect ecosystem benefits. By creating storage and supply benefits that do not rely on additional diversions from aquatic ecosystems, these new storage strategies increase the ability of water users to meet their needs and reduce conflicts with regulatory actions to adequately protect vulnerable ecosystems. Although these projects do not directly reduce the effects of other water projects on aquatic ecosystems, the growth of these projects is clearly beneficial, from an environmental perspective. These indirect benefits are not as tangible as those provided by dam removal or the installation of temperature-control devices; however, they are important, providing a new and balanced approach to water management. These indirect benefits have been recognized by the state legislature. For example, strategies that reduce reliance on aquatic ecosystems are included in the Delta Reform Act, as central to achieving the state's coequal goals for Delta management.

Integration of New Storage Strategies

As discussed above, before 1980, many storage projects included a narrow set of storage strategies, particularly on-stream storage, flood protection, and hydropower production. Since 1980, as the new strategies above have emerged, some storage projects now integrate a new set of storage strategies. One such example is the LADWP proposal to clean up contaminated groundwater in the San Fernando Valley to facilitate the storage of recycled water and local stormwater runoff. Another is the City of San Diego proposal to build new conveyance facilities to carry recycled water to an enlarged off-stream storage facility.

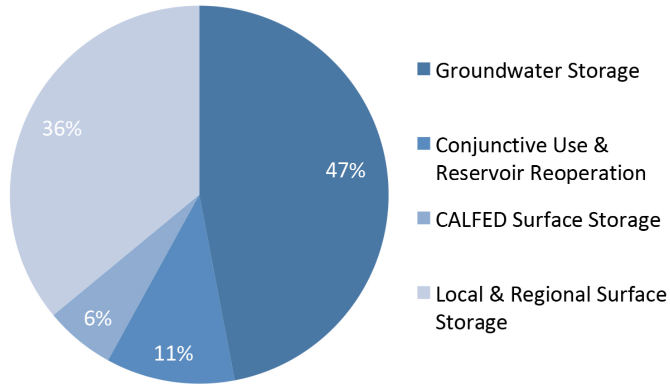

Figure 5 CWC 2015 scoping survey – proposed storage project by type

The California Water Commission conducted a scoping survey to identify potential candidates for Proposition 1 funding. Figure 5 summarizes the results of that survey, revealing that a large proportion of proposed projects incorporate the above new approaches to storage. A summary of these projects is included in Appendix A.

Finally, an analysis of the largest storage projects designed to serve the state's major cities over the past century confirmed the changes in storage strategies discussed here. The table in Appendix B demonstrates that the largest storage strategies for five urban areas, planned and constructed since 1980, reflect many of the new storage strategies discussed above.

Table 3 Characteristics of traditional and emerging storage strategies

Traditional storage (1923–1978)	Emerging strategies (post–1980)
On-stream storage	Off-stream, groundwater, and other infrastructure strategies to provide storage benefits Management changes to provide storage benefits
Primary reliance on major rivers and the Bay–Delta watershed as a water source	Greater use of non-traditional water sources (stormwater and recycled water) that reduce reliance on the Bay–Delta and other ecosystems
Focus on maximizing average deliveries	Increased focus on dry-year supply
Large, centralized storage far from end users	Distributed storage located closer to end users, with greater local control, and tailored to local needs and conditions
Broad ecosystem effects	More projects with direct and indirect ecosystem benefits, including storage retrofit and removal
Focus on supply, hydropower, and flood control	Integration of multiple new storage strategies and goals

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CONCLUSIONS: EMERGENCE OF A NEW 21ST CENTURY STORAGE PARADIGM

Since 1980, a new series of strategies for water storage emerged. Those strategies are dramatically different from the characteristics of storage projects built between 1923 and 1978 (Table 3).

Not all new storage projects exhibit all of these new characteristics, but, together, these emerging approaches demonstrate a need to rethink the fundamental definition of water storage.

In the past, indirect water-recycling projects, cleaning up contaminated aquifers, and the expansion of flood-conveyance capacity downstream of reservoirs have generally not been recognized as water storage projects. This is demonstrated in the recent document, *Integrating Storage in California's Changing Water System* (Lund et al. 2014), in which recycled water and other non-traditional water sources receive little analysis.

One the most dramatic examples of the trend toward a new storage paradigm is the City of San Diego's proposed recycling project (for details see Appendix A). This project proposes the construction of a new conveyance facility to tap into a non-traditional water supply (recycled water) in order to store water in an off-stream reservoir close to San Diego users. Thus, the water source, the location, and the design of this project are significantly different from the traditional storage strategies summarized in Table 3.

New Strategies are the Result of Changing Conditions

Some interests have asserted that the decline in the construction of new traditional surface storage projects is the result of the environmental community's advocacy efforts. Although there have been several high-profile advocacy efforts by the environmental community in opposition to new surface storage projects (e.g., the proposed Auburn Dam), the dramatic change of direction seen in storage planning and construction in California since 1980 is primarily the result of decisions by water managers to pursue projects that respond to the changed conditions they face today, in comparison with conditions between 1923 and 1978.

Public attitudes and environmental regulation can make the construction of new surface storage facilities more difficult than in the past. However, it is unlikely that future conditions will allow California to return to the traditional storage approach seen from 1923 to 1978.

Many California agricultural and urban water agencies are already using the new approaches to storage summarized here. The statewide water policy discussion should incorporate them as well. For example, these results should be considered in decisions regarding the investment of Proposition 1 storage funds, in debates about future water bonds, in future updates of the California Water Plan, and in other water policy forums.

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