MEETING OF THE BOARD OF DIRECTORS OF THE
MUNICIPAL WATER DISTRICT OF ORANGE COUNTY
Jointly with the
PLANNING & OPERATIONS COMMITTEE
December 2, 2019, 8:30 a.m.
Conference Room 101

P&O Committee:
Director Yoo Schneider, Chair
Director Tamaribuchi
Director Dick

Ex Officio Member: Director Barbre

Staff: R. Hunter, K. Seckel, J. Berg, H. De La Torre, K. Davanaugh, D. Harrison

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MWDOC Committee meetings are noticed and held as joint meetings of the Committee and the entire Board of Directors and all members of the Board of Directors may attend and participate in the discussion. Each Committee has designated Committee members, and other members of the Board are designated alternate committee members. If less than a quorum of the full Board is in attendance, the Board meeting will be adjourned for lack of a quorum and the meeting will proceed as a meeting of the Committee with those Committee members and alternate members in attendance acting as the Committee.

PUBLIC COMMENTS - Public comments on agenda items and items under the jurisdiction of the Committee should be made at this time.

ITEMS RECEIVED TOO LATE TO BE AGENDIZED - Determine there is a need to take immediate action on item(s) and that the need for action came to the attention of the District subsequent to the posting of the Agenda. (Requires a unanimous vote of the Committee)

ITEMS DISTRIBUTED TO THE BOARD LESS THAN 72 HOURS PRIOR TO MEETING -- Pursuant to Government Code section 54957.5, non-exempt public records that relate to open session agenda items and are distributed to a majority of the Board less than seventy-two (72) hours prior to the meeting will be available for public inspection in the lobby of the District's business office located at 18700 Ward Street, Fountain Valley, California 92708, during regular business hours. When practical, these public records will also be made available on the District's Internet Web site, accessible at http://www.mwdoc.com.

DISCUSSION ITEM

1. COMMENTS/OBSERVATIONS ON STORAGE IN CALIFORNIA, SOUTHERN CALIFORNIA AND CDM SMITH ANALYSIS OF THE COSTS AND BENEFITS OF NEW SURFACE STORAGE IN SOUTHERN CALIFORNIA

INFORMATION ITEMS (The following items are for informational purposes only – background information is included in the packet. Discussion is not necessary unless a Director requests.)

2. AMERICA'S WATER INFRASTRUCTURE ACT (AWIA) STATUS UPDATE

3. SANTA ANA REGIONAL WATER QUALITY CONTROL BOARD (SANTA ANA WATER BOARD) RECOMMENDATIONS REGARDING THE POSEIDON REGIONAL BOARD PERMITS AND OCEAN PLAN AMENDMENT COMPLIANCE

4. STATUS REPORTS
   a. Ongoing MWDOC Reliability and Engineering/Planning Projects
   b. WEROC
   c. Water Use Efficiency Projects

5. REVIEW OF ISSUES RELATED TO CONSTRUCTION PROGRAMS, WATER USE EFFICIENCY, FACILITY AND EQUIPMENT MAINTENANCE, WATER STORAGE, WATER QUALITY, CONJUNCTIVE USE PROGRAMS, EDUCATION, DISTRICT FACILITIES, and MEMBER-AGENCY RELATIONS

ADJOURNMENT

NOTE: At the discretion of the Committee, all items appearing on this agenda, whether or not expressly listed for action, may be deliberated, and may be subject to action by the Committee. On those items designated for Board action, the Committee reviews the items and makes a recommendation for final action to the full Board of Directors; final action will be taken by the Board of Directors. Agendas for Committee and Board meetings may be obtained from the District Secretary. Members of the public are advised that the Board consideration process includes consideration of each agenda item by one or more Committees indicated on the Board Action Sheet. Attendance at Committee meetings and the Board meeting considering an item consequently is advised.

Accommodations for the Disabled. Any person may make a request for a disability-related modification or accommodation needed for that person to be able to participate in the public meeting by telephoning Maribeth Goldsby, District Secretary, at (714) 963-3058, or writing to Municipal Water District of Orange County at P.O. Box 20895, Fountain Valley, CA 92728. Requests must specify the nature of the disability and the type of accommodation requested. A telephone number or other contact information should be included so that District staff may discuss appropriate arrangements. Persons requesting a disability-related accommodation should make the request with adequate time before the meeting for the District to provide the requested accommodation.

Item No. 1

DISCUSSION ITEM
December 2, 2019

TO: **Planning & Operations Committee**
(Directors Yoo Schneider, Dick, Tamaribuchi)

FROM: **Robert Hunter, General Manager**

Staff Contact: Karl Seckel

SUBJECT: **Comments/Observations on Storage in California, Southern California and CDM Smith Analysis of the Costs and Benefits of New Surface Storage in Southern California**

STAFF RECOMMENDATION

Staff recommends the Planning & Operations Committee receive and file this report.

COMMITTEE RECOMMENDATION

Committee recommends (To be determined at Committee Meeting)

SUMMARY

At the request of the Board, staff and consultant CDM Smith have evaluated the benefits and costs of a new surface storage reservoir located in Southern California. The results of this analysis indicate that a new MET surface reservoir with a storage volume of 400,000 acre-feet is not cost-effective. Even under the best modeling scenario in which the need for new MET water supply was coupled with available surplus water most of the time, the average marginal supply benefit would be in the neighborhood of 26,000 AFY by year 2050 and the unit cost would be $7,800/AF; about 11 times the current MET untreated water rate.

DETAILED REPORT

Introduction

In response to the modeling and analysis work conducted for the 2018 OC Water Reliability Study, the Board requested staff also evaluate the benefits of locating a new surface

<table>
<tr><td>Budgeted (Y/N): N/A</td><td colspan="2">Budgeted amount: N/A</td><td>Core ✓</td><td>Choice __</td></tr>
<tr><td colspan="2">Action item amount: N/A</td><td colspan="3">Line item: N/A</td></tr>
<tr><td colspan="5">Fiscal Impact (explain if unbudgeted):</td></tr>
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storage reservoir in Southern California. The thought was that additional surface storage would provide additional benefits in the form of capture of wet year water, when it is available, for carry-over or use during dry periods. To respond to this request, CDM Smith completed additional modeling work focused on such an evaluation. This report to the P&O Committee provides background information on storage in California and Southern California, as it is a complex topic and there is often confusion regarding the types and uses of storage. The report also provides an overview of the findings from the CDM Smith report along with several conclusions/recommendations. Because of the complexity of this topic, a number of references have been provided.

Discussion of Water Storage in California and Southern California

Several general thoughts are provided below:

1. When considering regional water storage in the State of California or for Southern California, it is important to clarify that water is stored for different purposes and functions. This report focuses on surface storage for yield purposes within the regional systems and does not get into the specific daily, seasonal, and fire-fighting storage needs of retail agencies. The types of regional storage are:
    a. **Storage for water supply yield purposes** to capture water when it is available, typically during wet-year periods for subsequent use during dry-years and extended drought periods (typically 2 to 6 years in duration).
    b. **Storage for emergency purposes** to help meet demands for weeks, months or years following an outage of all or a part of the regional water delivery system. With respect to storage of emergency water in reservoirs in Southern California, MET recently adopted an updated target to increase the amount of water in storage for emergencies from 630,000 AF to 750,000 AF. It was also recommended that the target amount be reviewed during the IRP and when additional information becomes available on the outage and recovery duration of facilities due to impacts from earthquakes.
2. Storage for water supply yield purposes can be accomplished by surface reservoirs or through groundwater banking. Each type of storage has its costs, advantages and disadvantages. Surface reservoirs can be further defined as on-stream or off-stream storage; and again, each with its costs, advantages and disadvantages.
3. Building new water storage has historically increased water supplies during droughts, but at varying levels of cost-effectiveness. The trend has been that the most recent storage expansion is more expensive than the previous storage expansion. With future changes in environmental regulations, climate and water demands, evaluation of new storage becomes more complicated than in the past.
4. Expanding storage usually increases water deliveries by at least some amount, but does not necessarily increase the cost-effectiveness of the water deliveries – in fact, most storage expansions are more costly per increment than the previous storage increment developed.

5. The cost-effectiveness of storage for water supply yield is a function of: (1) cost of constructing storage and the cost of getting water into and out of storage, (2) the expected need for new water supply developed from the storage, and (3) the costs of alternative supplies to what the storage option provides.

6. There are large differences in storage opportunities and constraints between locations 1) North of the Delta, 2) South of the Delta (in the Central Valley) and 3) South of the Tehachapis (in Southern California).

   a. North of Delta – storage is mostly constrained by hydrology, senior water rights and environmental or regulatory issues.

   b. South of Delta (including portions of the MET system) - is also constrained by hydrology, but storage is mostly constrained by environmental and regulatory constraints on the State Water Project (SWP) system conveyance capacity, and the amount of water remaining in the system for storage after North of Delta storage is factored into SWP "Table A" allocations. Maximum pumping out of the Delta is limited by the capacity of the Delta pumps to no more than the 15,000 cfs. Often, pumping out of the Delta is limited to much lower levels due to fisheries and water quality issues. The purpose of the Delta Conveyance Project is to improve the operations of water flowing both through and under the Delta to eliminate some of the restrictions and improve the ability of the SWP to operate as a storm water capture facility. The Delta Conveyance Project, paired with complementary projects, provides improvements to the Delta and opportunities for storage south of the Delta during wet periods. However, even though significant volumes of water may be available during wet periods, export pumping from the Delta is limited to 15,000 cfs.

   c. Storage in Southern California will always be conveyance constrained by the conveyance capabilities of the SWP and the capacity of the terminal reservoirs to capture the water.

7. Most of the locations that facilitate effective capture of water that are environmentally easy to permit in California already have surface reservoirs. The type of storage (on-stream, off-stream and groundwater) impacts the effectiveness of storage capture (storage puts) and withdrawals (storage takes). Typically, on-stream storage puts can occur as fast as the river delivers it and the deliveries out of storage are controlled by the outlet structure design. Typically, off-stream storage and groundwater banking have more constraints in terms of storage puts and takes.

8. More storage is always beneficial from a supply standpoint, but needs to be evaluated as to the costs of the yield provided by the new storage. Decisions on storage should be approached from a business decision perspective based on the cost-effectiveness of the storage under consideration compared to other alternatives to storage; including demand curtailment during water shortage events.

9. Climate change and warming conditions will affect storage and the value of storage. Reduced snowpack, more precipitation in the form of rain, and earlier runoff (and

less storage in the form of snow) will make capturing runoff more difficult than in the past. The State Water Project has 21 Primary reservoirs with a storage capacity of 5.8 MAF[1]. Overall, California has about 1,400 regulated reservoirs with about 42 MAF of storage capacity[2].

10. Surprisingly, at least one of the reports[3] seems to indicate that the warming of the climate and the loss of the snowpack might be able to be managed without catastrophic impacts, due to the large number of reservoirs that already exist in California. Another notes that warming trends could make it difficult to fill reservoirs during certain periods based on the availability of supplies. Storage is a complicated issue in the State of California, especially when viewed from the perspective of what we might face in the future.

CDM-Smith Modeling Analysis

The analysis performed by CDM-Smith tests the value of having a conceptual surface reservoir in the amount of 400,000 AF located near Diamond Valley Lake in Southern California under the conditions modeled in the 2018 OC Water Reliability Study. This evaluation was requested by the Board as part of the OC Water Reliability Study.

Attached is the report by CDM Smith in its entirety. Also attached is a Powerpoint presentation that provides information relevant to storage and to the CDM Analysis.

CDM-Smith Conclusion:

The results of this analysis indicate that a new MET surface reservoir with a storage volume of 400,000 acre-feet is not cost-feasible. Even under the best modeling scenario (Scenario 3) in which the need for new MET water supply was coupled with available surplus water most of the time, the average marginal supply benefit would be in the neighborhood of 26,000 AFY by year 2050. Under this scenario, the unit cost would be $7,800/AF, about 11 times the current MET untreated water rate. Because the cost of surface storage is so site specific, the question may be raised if the capital cost of storage was over-stated, or that a smaller reservoir may be more cost-effective. If the actual cost of the reservoir is higher or lower, the unit numbers would track accordingly.

A smaller reservoir would cost less, but would also capture less water. A sensitivity check indicated the unit costs for a 200,000 AF reservoir would be 40% to 50% of the unit costs

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[1] DWR California State Water Project At A Glance (April 2011), https://water.ca.gov/LegacyFiles/recreation/brochures/pdf/swp_glance.pdf.

[2] Jay Lund, et. al. Integrating Storage in California's Changing Water System (Nov. 2014), https://watershed.ucdavis.edu/files/biblio/Storage_White_Paper_20Nov2014.pdf

[3] Lund, J.R. (2011), "Water Storage in California," California WaterBlog, Sept. 13, 2011, https://californiawaterblog.com/2011/09/13/water-storage-in-california-2/

for a 400,000 AF reservoir, but the costs would still be greater than other supply alternatives available to OC, including seawater desalination.

Discussion of the CDM Smith Results of the Modeling Work

When considering the addition of new storage for supply yield purposes, the proper analysis to conduct is to make the new reservoir the last recipient of water among the other storage locations and to make the reservoir the last use of water out of storage – this tests the marginal cost-effectiveness of the storage location. When a storage location is constructed and put into operation, the two outcomes you do not want to have occur, is (1) for the storage reservoir to fill and remain full forever more (this is an indication that the storage is not needed), nor do you want (2) the reservoir to remain empty forever more (this is an indication that there are not enough supply sources to enable use of the reservoir). A storage for yield location that is emptying and filling periodically is one that is providing a supply yield over time. Determining whether the supply yield is cost-effective or not requires comparing the cost per AF of yield to other alternatives. In this analysis, the high cost per yield determined by the study, indicated that having an additional surface storage in Southern California under the modeling conducted for the 2018 OC Water Reliability Study is not cost-effective. Other options that should be considered would be for MET to develop a comprehensive program to improve coordination of storage between MET and the groundwater basins in Southern California. Historically, MET has encountered difficulty in successfully implementing groundwater storage programs in Southern California, outside of Orange County.

Furthermore, MET's recent demand trends have remained low. If this trend continues for the long run, MET may be in the position of being more reliable than in the past. The 2018 OC Water Reliability Study used the 2015 MET demand forecast, which was then influenced by our climate modeling to between 2% and 5% higher; rather than using the low demands that MET is recently experiencing. Using a lower demand forecast into the storage analysis included herein would result in higher unit costs of storage. Using higher demands would result in less water being able to be stored. Prior to any further analyses, MET should conduct an analysis of the future demand trends to more accurately project where they are headed.

Staff believes the storage question is an important one for the future and suggests requesting MET to include the following questions into the upcoming IRP:

- How does climate change impact future needs for storage?
- How much storage is enough storage for MET?
- Are there any remaining ideal locations for new storage?
- What is the cost-effectiveness for new storage (reservoir or groundwater)?

Additional Staff Comments

1. Staff reviewed the results of the CDM-Smith modeling with MET staff familiar with the MET IRP modeling and although they could not verify the specific operations of the CDM-Smith modeling, they were of the belief that MET's modeling would provide similar results. Because of the changes in demand, staff suggests having MET further examine the storage issue as part of their IRP. It should be noted that MET has made changes over the years as they have developed additional historical perspectives. Earlier this year, the MET Board approved an expansion to the AVEK groundwater storage program in the Central Valley to add 280,000 AF of storage with a maximum put and take of 70,000 AF per year. This was in direct response to the low SWP allocation in 2014 that was zero for part of the year and only reached 5% which left MET's SWP only service area vulnerable. The AVEK storage was not included in the CDM-Smith modeling as it was added after the 2018 OC Water Reliability Study.

2. The Board requested information on whether or not MET had ever **not** been able to take their full "Table A" entitlements in any year and also asked if the storage coordination arrangement between MET and LADWP in 2017 had resulted in an ability for MET to capture all water or if any water was lost?

   In discussions with MET staff, it was noted that LADWP and MET entered into an one-year agreement in 2017 to store excess water from the Los Angeles Aqueduct, due to a significantly high Owens Valley runoff year. The agreement clearly stated that MET had full discretion over whether to take this water from LADWP and that LADWP's water would be the "first to spill" so as not to disrupt MET's ability to capture its own supplies. This means the risk of any water loss through this transaction would be applied to LAWDP. However, our understanding is that LADWP never activated the agreement (except for a small amount of "test" storage) and so no water was stored for LADWP and we are not aware of any water losses on either side.

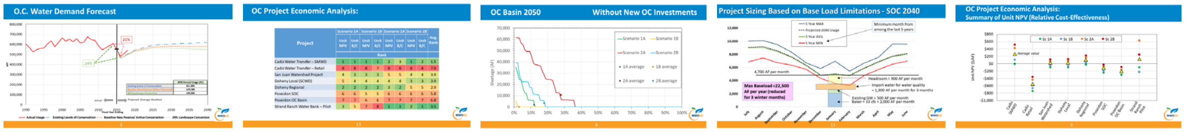
   Further discussions with MET indicated that since 2000, MET has rarely been in a situation where all of its SWP deliveries were not stored. For one, the SWP "Table A" allocation needs to be very high and second, the key State reservoirs need to be in a position where they may spill. Under these circumstances, it is possible for MET to not take 100% of their "Table A" water; if this occurs there is an opportunity for MET to recover the water through Article 21 water or through carry-over water. For example, when San Luis Reservoir is nearly full, each SWP contractor's carryover amount within the reservoir must be moved out of storage or they potentially risk losing the water. However at the same time, DWR announces the availability of Article 21 water (surplus water); MET is one of the few SWP contractors that is often able to take large amounts of Article 21 water and put it into storage. So, although there may be instances in which MET can lose carryover storage or not take full "Table A" entitlements, MET often has the ability to recover a good share of it.

It is also important to note that as MET continues to add or modify storage agreements with other SWP contractors, the chances of any losses in the future will be remote or eliminated. The recent AVEK storage agreement adds 280,000 AF to MET's storage capacity with an ability to "put" 70,000 AF in any given year. In addition, MET is working with Mojave Water District to increase its storage capacity. Just these two storage agreements alone will greatly assure MET will not be in a position of losing water in the future.

Further reading

The documents referenced below discuss the complex issue of storage for supply yield in California:

1. Lund, J.R. (2012), "Expanding Water Storage Capacity in California," California WaterBlog, Feb. 22, 2012, https://californiawaterblog.com/2012/02/22/expanding-water-storage-capacity-in-california/
2. Lund, J.R. (2011), "Water Storage in California," California WaterBlog, Sept. 13, 2011, https://californiawaterblog.com/2011/09/13/water-storage-in-california-2/
3. Lund, J.R., Hall, M. and Saracino, A., "Shaping water storage in California," California WaterBlog, Nov. 20, 2014, UC Davis Center for Watershed Sciences, https://californiawaterblog.com/2014/11/20/shaping-water-storage-in-california/
4. Jay Lund, Armin Munevar, Ali Taghavi, Maurice Hall & Anthony Saracino, Integrating Storage in California's Changing Water System (Nov. 2014), available at https://watershed.ucdavis.edu/files/biblio/Storage_White_Paper_20Nov2014.pdf .



Evaluation of a NEW Surface Storage Reservoir in Southern California for Supply Yield Purposes

MWDOC P&O Committee

December 2, 2019

Purposes and Types of Storage

- **Storage for Supply Yield** – storage is periodically cycled in a reservoir from full (during wet periods) to empty (during dry periods) to provide supply yield
- **Storage for Emergencies** – water remains in storage reserved for emergency use
- Types of Storage
  - On Stream Surface Reservoir Storage
  - Off Stream Surface Reservoir Storage
  - Groundwater Storage or Banking

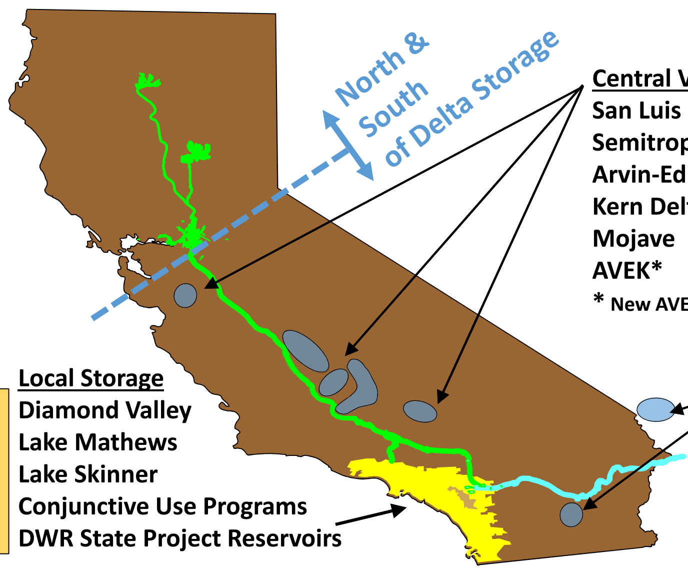
As an example, Diamond Valley Reservoir provides a combination of:
- **Emergency Storage &**
- **Storage for Supply Yield**

Each type of storage has its advantages and disadvantages

Background on Storage for Supply Yield Purposes

- Building new storage has historically increased water supplies during droughts, but at varying levels of cost-effectiveness
- The cost-effectiveness depends on:
  - The cost of building the storage plus the costs of getting water into and out of storage
  - The need for a new water supply
  - Alternatives to providing the equivalent supply increment
- Expanding storage usually increases water deliveries, but not always in a cost-effective manner, e.g., if you are already capturing water, new or expanded storage can only capture water that otherwise would not have been captured in other storage locations

MET Flexible Storage Locations for Supply Yield
(emergency supplies and Desert/Coachella removed for discussion of supply yield)



Central Valley/SWP Storage
San Luis Carryover
Semitropic
Arvin-Edison
Kern Delta
Mojave
AVEK*

1.2 MAF Flexible above Emergency

* New AVEK storage of 280,000 AF not included

Local Storage
Diamond Valley
Lake Mathews
Lake Skinner
Conjunctive Use Programs
DWR State Project Reservoirs

1.3 MAF Flexible above Emergency

CRA Storage
Desert/Coachella Advance Delivery & Lake Mead ICS

1.6 MAF Flexible

Differences in Storage Opportunities and Constraints

- **North of Delta**
  - Mainly subject to hydrology, senior water users, and environmental constraints
- **South of Delta**
  - Constrained by environmental and water quality issues of getting water across the Delta; also constrained by the Delta Export pumping capacity and regulations that dictate the pumping operations
  - Purpose of the Delta Conveyance is to improve this situation
- **Southern California**
  - Constrained by SWP deliveries and terminal storage capacity

Comments on Storage for Supply Yield

- **SWP has 21 primary reservoirs with a storage capacity of 5.8 maf**
- **Overall, California has about 1,400 reservoirs, with a combined storage capacity of 42 maf**
- **Climate change:**
  - Capturing water will be more difficult
  - May lose some supply yield if additional reservoirs or groundwater storage programs are not developed
  - Higher demands will result in less water to store
  - Lower demands will result in more water to store

CDM Smith Analysis Assumptions

Table 1. New MET Reservoir Assumptions

Reservoir Assumption	Value
Total Storage Volume	400,000 Acre-Foot
Put Capacity (Max Annual Capacity)	400,000 Acre-Feet/Year
Withdrawal Capacity (Max Annual Capacity)	400,000 Acre-feet/Year
Priority for Filling Reservoir Priority for Withdrawals from Reservoir	After All Existing Reservoirs and Groundwater Banking Programs
Total Capital Cost (2018 dollars)	$3.3 Billion
Annual O&M Cost (2018 dollars)	$20 Million/Year

To understand the marginal improvement in storage capability new storage provides, water deliveries go to all other storage first and storage withdrawals occur after all other storage withdrawals

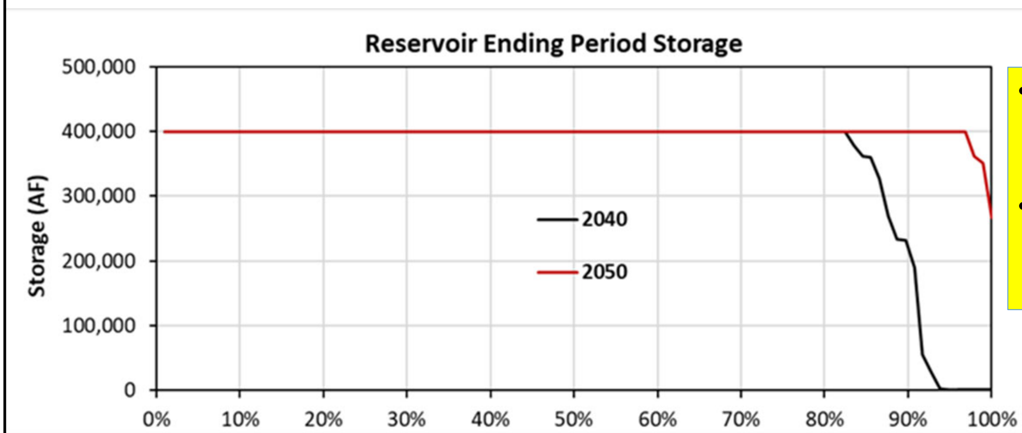
CDM Smith Analysis Assumptions

Table 2. New MET Reservoir Modeling Scenarios

Scenario	Climate Change Impacts	MET Carson Indirect Potable Reuse (IPR)	Delta Conveyance	Scenario Supply Outlook
Scenario 1	Minimal	Online by 2029	Online by 2035	Best Supply
Scenario 2	Significant	Online by 2029	Online by 2035	2nd Best Supply
Scenario 3	Significant	Not Implemented	Online by 2035	Middle Scenario
Scenario 4	Significant	Online by 2029	Not Implemented	Next to Worst Supply
Scenario 5	Significant	Not Implemented	Not Implemented	Worst Supply

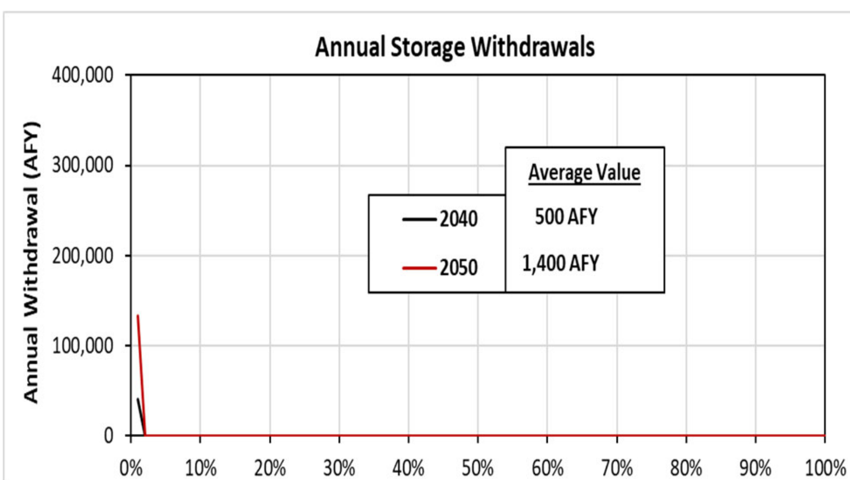
The supply and demand scenario determines the availability of water for storage

Scenario 1, minimal climate change, Carson on by 2029, WaterFix on by 2035 – Best water supply outlook



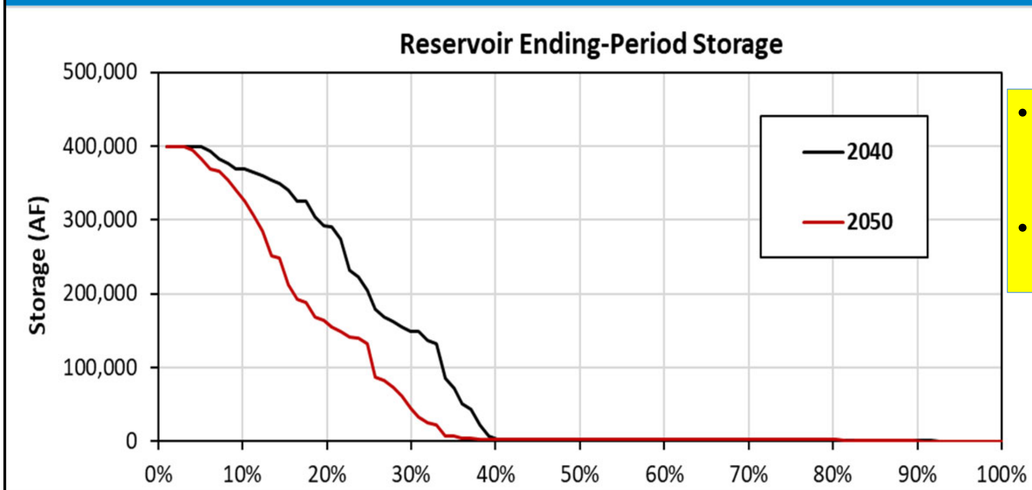
- Reservoir remains full most of the time;
- Not much cycling of reservoir storage

Scenario 1, minimal climate change, Carson on by 2029, WaterFix on by 2035 – Best water supply outlook



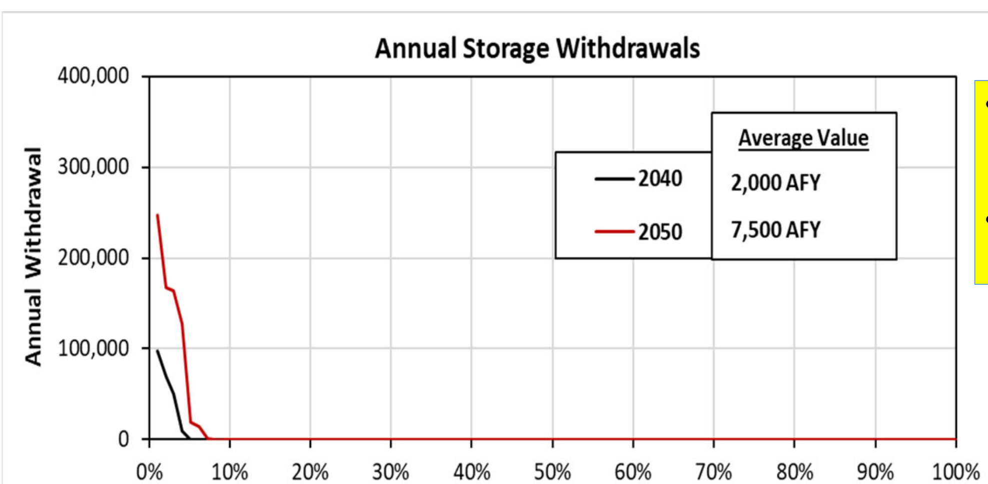
- Reservoir not used often to provide supply < 5% of the time;
- Supply yields are small

Scenario 5, significant climate change, Carson not implemented, WaterFix not implemented – Worst water supply outlook



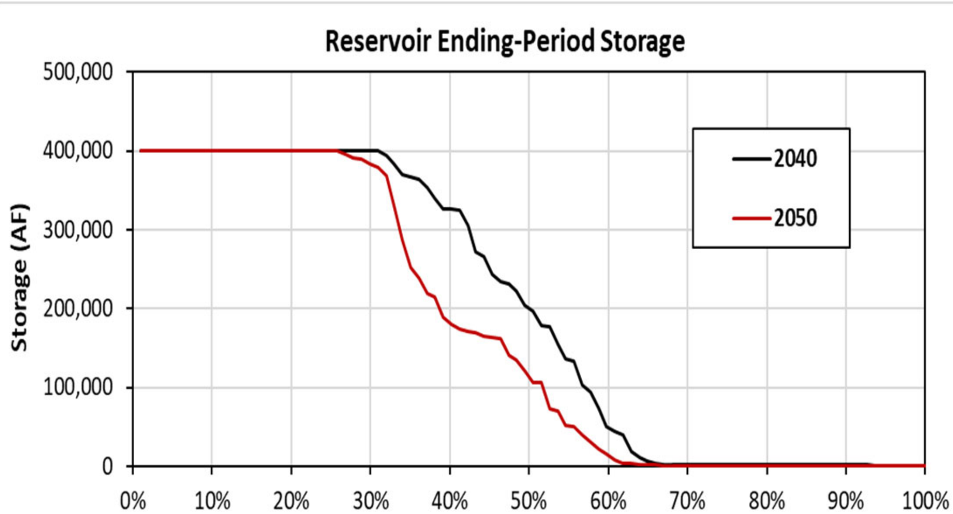
- Reservoir remains empty 60% of the time;
- Fills less than 5% of the time

Scenario 5, significant climate change, Carson not implemented, WaterFix not implemented – Worst water supply outlook



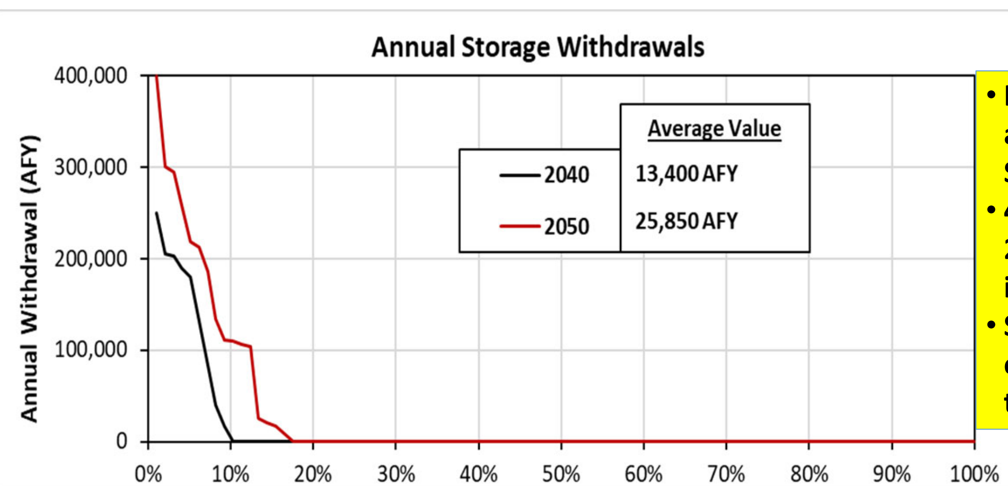
- Supply yield is only used 7% of the time
- Supply yields are small

Scenario 3, significant climate change, Carson not implemented, WaterFix on line by 2035 – Medium water supply outlook



- **Reservoir is full 30% of the time and empty 35% of the time**

Scenario 3, significant climate change, Carson not implemented, WaterFix on line by 2035 – Medium water supply outlook



- **Highest yield among 5 Scenarios;**
- **400,000 AF draw 2% of the time (1 in 50 years)**
- **Supply yield only occurs 18% of the time**

Summary of Scenarios 1, 3 & 5

Table 3. Unit Cost of New MET Reservoir

Parameter	Scenario 1 Best Supply Outlook	Scenario 3 Medium Supply Outlook	Scenario 5 Worst Supply Outlook
Average Supply in 2040 (AFY)	500	13,400	2,000
Average Supply in 2050 (AFY)	1,400	25,850	7,500
Max Withdrawal in 2040 (AFY)	50,000	250,000	99,000
Max Withdrawal in 2050 (AFY)	130,000	400,000	250,000
Unit Cost in 2040 ($/AF)	$403,000	$15,000	$101,000
Unit cost in 2050 ($/AF)	$144,000	$7,800	$27,000

Note that a one-time withdrawal of 200,000 AF to 400,000 AF averaged over a 30-year period would result in an average yield of 6,700 AF per year to 13,300 AF per year

- Unit costs of storage are not cost-competitive

Conclusions

- A new MET surface reservoir in Southern California with a storage volume of 400,000 acre-feet is not cost-effective.
- Under the best modeling scenario (Scenario 3) in which the need for new MET water supply was coupled with available surplus water most of the time, the average marginal supply benefit would be in the neighborhood of 26,000 AFY by year 2050.
- The lowest unit cost would be $7,800/AF (this is the best scenario in 2050)

Sensitivity Analyses

- Without a site specific analysis it is difficult to estimate the actual costs of a reservoir. If the actual cost of the reservoir is higher or lower, the unit numbers would track accordingly.
- A smaller 200,000 AF reservoir would cost less, but would also capture less water. A sensitivity check indicated the unit costs for a 200,000 AF reservoir would be 40% to 50% of the costs for a 400,000 AF reservoir, but the costs would still be greater than other supply alternatives available to OC, including seawater desalination.

Recommendations

- If additional storage is to be added within the MET system to provide additional supply yield, it must provide cost-effective yield at a cost lower than or commensurate with other alternatives.
- Groundwater storage within MET may be the next beneficial storage if terms and conditions can be agreed to. MET has historically encountered difficulty in successfully implementing groundwater storage programs in Southern California, outside of Orange County.
- Demand trends must be updated to perform any additional analyses.

MET's upcoming IRP should address the following questions:

1. How does climate change impact future needs for storage?
2. How much storage is enough storage?
3. Are there any remaining ideal locations for new surface storage?
4. What is the cost-effectiveness for new storage (reservoir or groundwater)?

Memorandum

To: *Karl Seckel, MWDOC*

From: *Dan Rodrigo, CDM Smith*

Date: *November 25, 2019*

Subject: *Evaluation of New MET Surface Reservoir*

Purpose

During the preparation of the 2018 Orange County Water Reliability Study (2018 OC Study), a conceptualized new MET surface reservoir was evaluated in terms of overall reliability and cost impacts to MET, and how the new reservoir affected future water reliability for Orange County. As there is interest in this potential new reservoir by some MWDOC Board members, CDM Smith was authorized to evaluate in greater detail the marginal cost and benefit of such a project. The results presented here show the simulated use of the reservoir and estimated unit cost for the project.

Evaluation Assumptions

The assumptions for the new reservoir project are summarized in **Table 1**. For this evaluation, this new MET reservoir would be completely dedicated for drought storage, meaning no capacity of the reservoir would be reserved for seismic or system emergencies. This assumption was made because MET is already in compliance with retaining 750,000 AF of storage it its system south of the Tehachapis, for emergency use. Hence, the purpose of the new reservoir was evaluated based on its capability to store water during wet years and to utilize the water during dry years. To properly evaluate the costs and benefits, water goes into the reservoir only after other storage accounts are filled and water coming out of the reservoir occurs whenever all other sources of storage have been utilized.

Table 1. New MET Reservoir Assumptions

Reservoir Assumption	Value
Total Storage Volume	400,000 Acre-Foot
Put Capacity (Max Annual Capacity)	400,000 Acre-Feet/Year
Withdrawal Capacity (Max Annual Capacity)	400,000 Acre-feet/Year
Priority for Filling Reservoir Priority for Withdrawals from Reservoir	After All Existing Reservoirs and Groundwater Banking Programs
Total Capital Cost (2018 dollars)	$3.3 Billion
Annual O&M Cost (2018 dollars)	$20 Million/Year

To evaluate the actual supply yield for this new MET reservoir, the OC WEAP model developed for the 2018 OC Study was used. This model estimates the **probability** of available water for storage in the new reservoir, the **probability** of water need, and the **probability** of reservoir withdrawals from the new reservoir.

Factors that influence these **probabilities** include: (1) hydrology of State Water Project and Colorado River systems: (2) potential climate change; and (3) implementation of MET's Carson Regional Indirect Potable Reuse (Carson IPR) project and the Delta Conveyance project (previously called California WaterFix in the 2018 OC Study). It should be noted that the WEAP modeling is not set up as an optimization tool, but the data should provide a reasonable evaluation of the economy of the reservoir. Because of the uncertainties of these three influencing factors, CDM Smith developed five (5) modeling scenarios, which are summarized in **Table 2** spanning the best-case and worse-case water supply planning scenarios used for the 2018 OC Study.

Table 2. New MET Reservoir Modeling Scenarios

Scenario	Climate Change Impacts	MET Carson Indirect Potable Reuse (IPR)	Delta Conveyance	Overall Water Supply Outlook
Scenario 1	Minimal	Online by 2029	Online by 2035	Best Supply
Scenario 2	Significant	Online by 2029	Online by 2035	2nd Best Supply
Scenario 3	Significant	Not Implemented	Online by 2035	Middle Supply
Scenario 4	Significant	Online by 2029	Not Implemented	2nd Worst Supply
Scenario 5	Significant	Not Implemented	Not Implemented	Worst Supply

Evaluation Results

Scenario 1 – Both MET Carson IPR and Delta Conveyance Implemented, with Minimal Climate Change Impacts

Figure 1A presents the probability of ending-period storage for the new reservoir for Scenario 1. This is a function of how much surplus water supply is available after meeting MET water demands and the filling of existing MET storage (reservoir and groundwater).

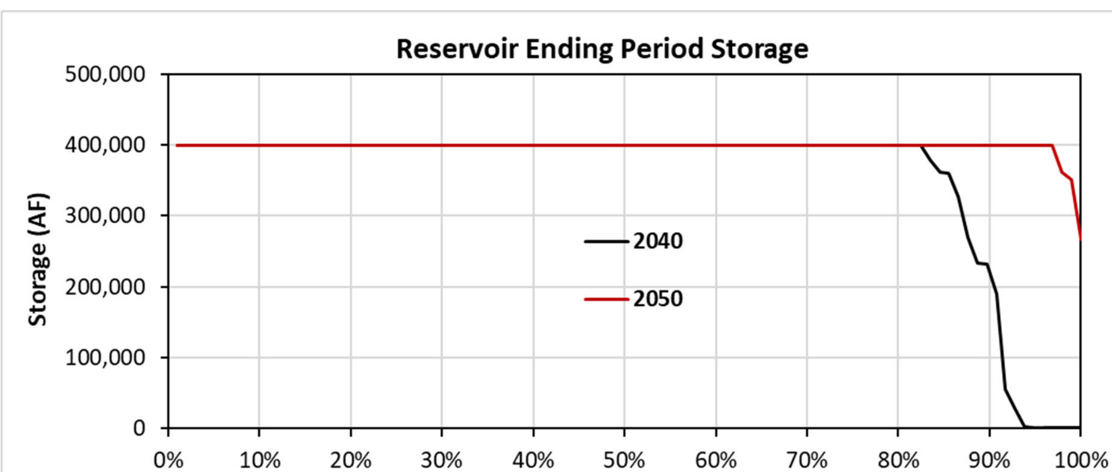


Figure 1A. Ending Period Storage for Scenario 1

In year 2040 for Scenario 1, it is estimated that the new reservoir would be at full storage volume approximately 82% of the time; while in year 2050 the new reservoir would be at full storage volume approximately 97% of the time. In 2040, it is estimated that the reservoir would be empty approximately 7% of the time; while in 2050 the reservoir would be never be empty.

Figure 1B presents the probability of annual storage withdrawals for Scenario 1, which represents supply yield for the reservoir. This is a function of how much water is stored in the reservoir and the probability that there is an additional need for new MET supply.

The combination of the two Figures 1A and 1B (and similar figures for the other scenarios), Reservoir Ending Period Storage and the Annual Storage Withdrawals tell the story of how the reservoir is used over time. Unlike a storage that is designed simply to provide emergency storage that we might like to see full 100% of the time until an emergency occurs, an investment in a storage reservoir for supply yield means that we want to see the reservoir being used so we would want to examine the combination of these two metrics. The two extremes we would not want to see is a reservoir that is always full or a reservoir that is always empty. That is why this analysis is not necessarily intuitive. Looking at the combination of the figures provides a more complete understanding. Based on past modeling applications, an ending period storage of 30% to 50% would be a good target. The more withdrawals that occur, the better off the economics of the reservoir investment.

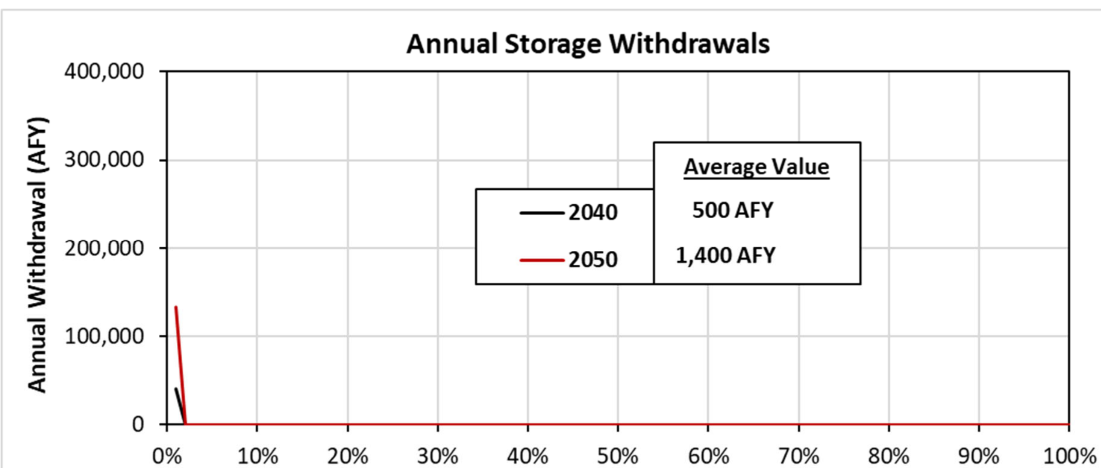


Figure 1B. Storage Withdrawals for Scenario 1

For Scenario 1, maximum reservoir withdrawals never exceed 50,000 AFY in 2040 and 130,000 AFY in 2050. The average reservoir withdrawals (across all hydrologic conditions) are 500 AFY in 2040 and 1,400 AFY in 2050.

The use of the new MET reservoir in Scenario 1 is constrained by the fact that additional water supplies are <u>not</u> needed 95% of the time, as both the MET Carson IPR and Delta Conveyance are implemented, and minimal climate change impacts is assumed. This scenario represents the worst condition for new storage as there simply is not enough need for the water.

Scenario 2 –MET Carson IPR and Delta Conveyance Implemented, with Significant Climate Change

Figure 2A presents the probability of ending-period storage for the new reservoir for Scenario 2. This is a function of how much surplus water supply is available after meeting MET water demands and the filling of existing MET storage (reservoir and groundwater).

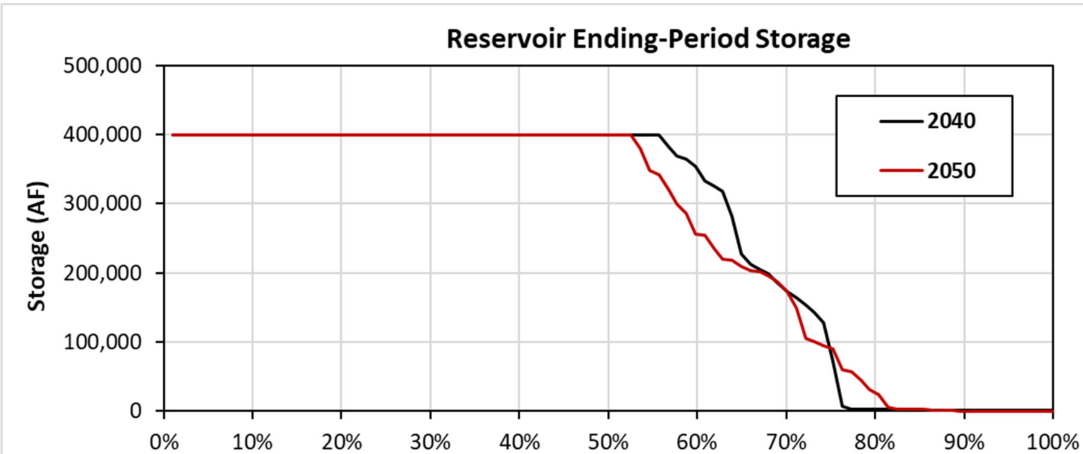


Figure 2A. Ending Period Storage for Scenario 2

In year 2040 for Scenario 2, it is estimated that the new reservoir would be at full storage volume approximately 52% of the time; while in year 2050 the new reservoir would be at full storage volume approximately 55% of the time. In 2040, it is estimated that the reservoir would be empty approximately 25% of the time; while in 2050 the reservoir would be empty approximately 19% of the time.

Figure 2B presents the probability of annual storage withdrawals for Scenario 2, which represents supply yield for the reservoir. This is a function of how much water is stored in the reservoir and the probability that there is an additional need for new MET supply.

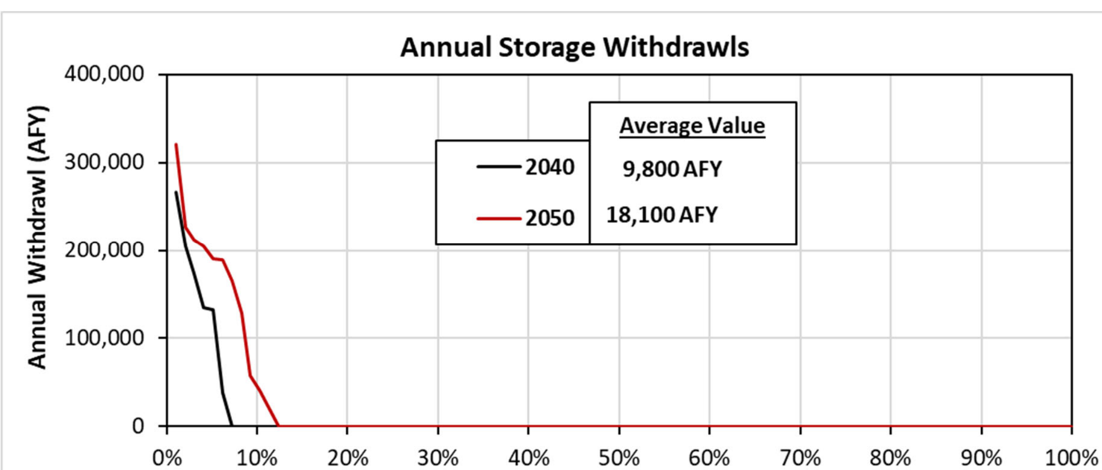


Figure 2B. Storage Withdrawals for Scenario 2

For Scenario 2, maximum reservoir withdrawals never exceed 280,000 AFY in 2040 and 310,000 AFY in 2050. The average reservoir withdrawals (across all hydrologic conditions) are 9,800 AFY in 2040 and 18,100 AFY in 2050.

The use of the new MET reservoir in Scenario 2 is mostly constrained by the fact that additional water supplies are not needed 85% of the time, as both the MET Carson IPR and Delta Conveyance are implemented (but now with significant climate change assumed). However, there are a few times in which the timing of droughts comes right after reservoir levels are not full, which does constrain reservoir withdrawals in those instances.

Scenario 3 – No MET Carson IPR, but Delta Conveyance Implemented, with Significant Climate Change

Figure 3A presents the probability of ending-period storage for the new reservoir for Scenario 3. This is a function of how much surplus water supply is available after meeting MET water demands and the filling of existing MET storage (reservoir and groundwater).

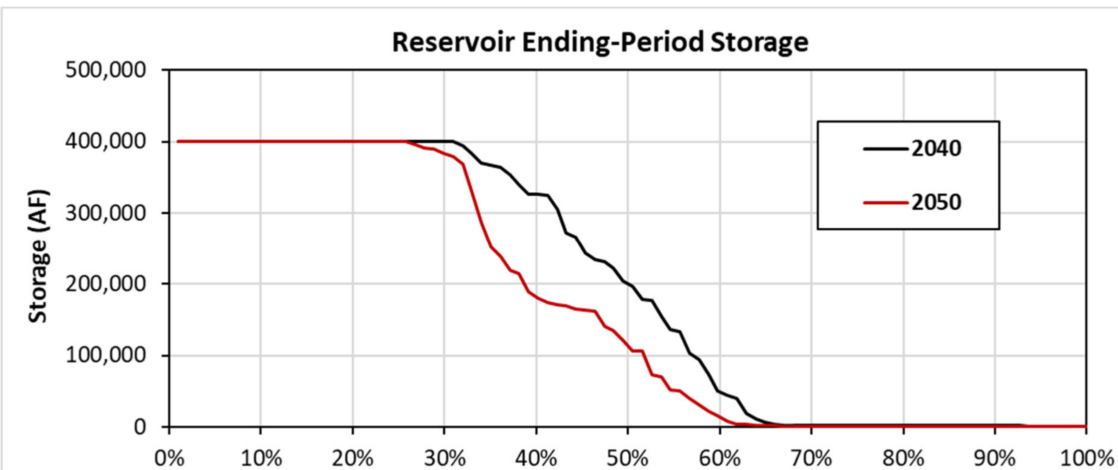


Figure 3A. Ending Period Storage for Scenario 3

In year 2040 for Scenario 3, it is estimated that the new reservoir would be at full storage volume approximately 30% of the time; while in year 2050 the new reservoir would be at full storage volume approximately 26% of the time. In 2040, it is estimated that the reservoir would be empty approximately 35% of the time; while in 2050 the reservoir would be empty approximately 38% of the time.

Figure 3B presents the probability of annual storage withdrawals for Scenario 3, which represents supply yield for the reservoir. This is a function of how much water is stored in the reservoir and the probability that there is an additional need for new MET supply.

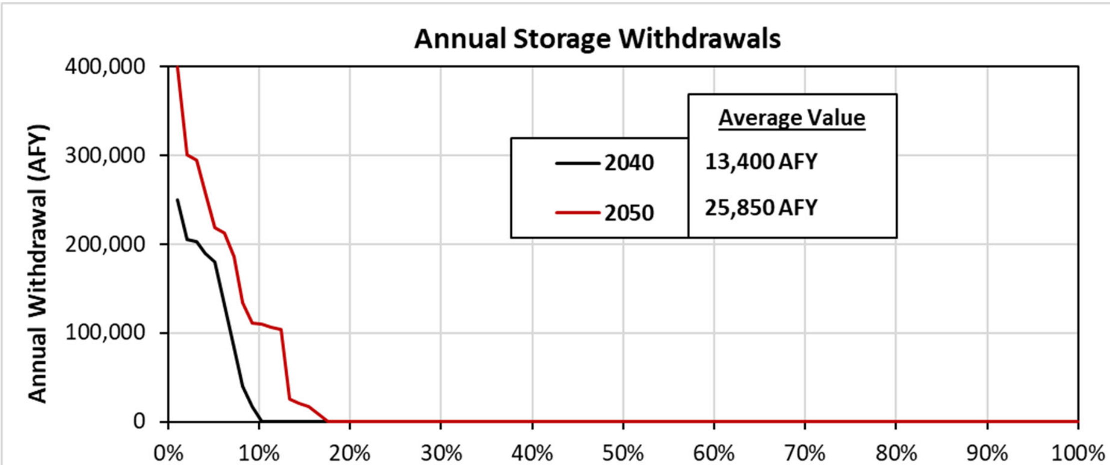


Figure 3B. Storage Withdrawals for Scenario 3

For Scenario 3, maximum reservoir withdrawals never exceed 250,000 AFY in 2040 and 400,000 AFY in 2050. The average reservoir withdrawals (across all hydrologic conditions) are 13,400 AFY in 2040 and 25,850 AFY in 2050.

The use of the new MET reservoir in Scenario 3 is mostly constrained by not always having adequate storage when droughts occur, as a result of not having the Carson IPR project implemented. However, in this scenario the need for additional water supply is greater—making Scenario 3 the best condition for new storage.

Scenario 4 –MET Carson IPR Implemented, but No Delta Conveyance, with Significant Climate Change

Figure 4A presents the probability of ending-period storage for the new reservoir for Scenario 4. This is a function of how much surplus water supply is available after meeting MET water demands and the filling of existing MET storage (reservoir and groundwater).

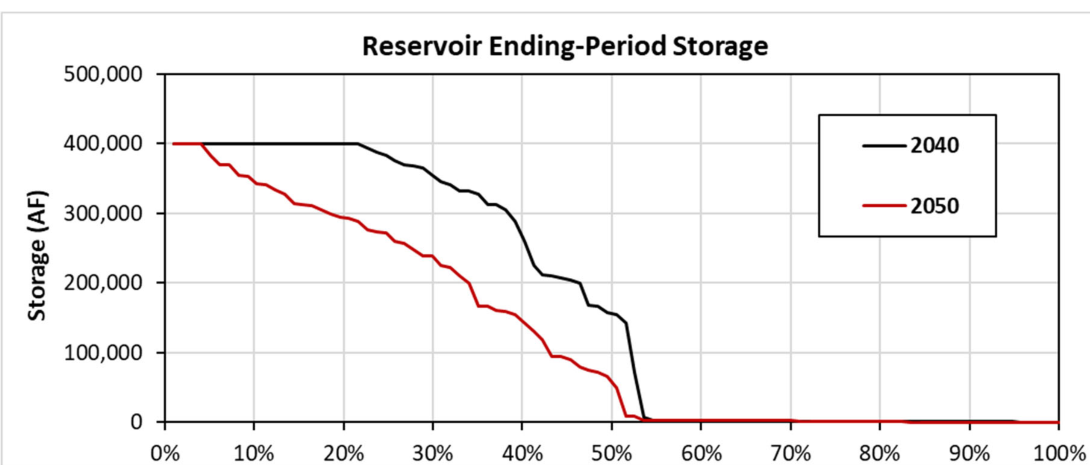


Figure 4A. Ending Period Storage for Scenario 4

In year 2040 for Scenario 4, it is estimated that the new reservoir would be at full storage volume approximately 21% of the time; while in year 2050 the new reservoir would be at full storage volume approximately 5% of the time. In 2040, it is estimated that the reservoir would be empty approximately 46% of the time; while in 2050 the reservoir would be empty approximately 48% of the time.

Figure 4B presents the probability of annual storage withdrawals for Scenario 4, which represents supply yield for the reservoir. This is a function of how much water is stored in the reservoir and the probability that there is an additional need for new MET supply.

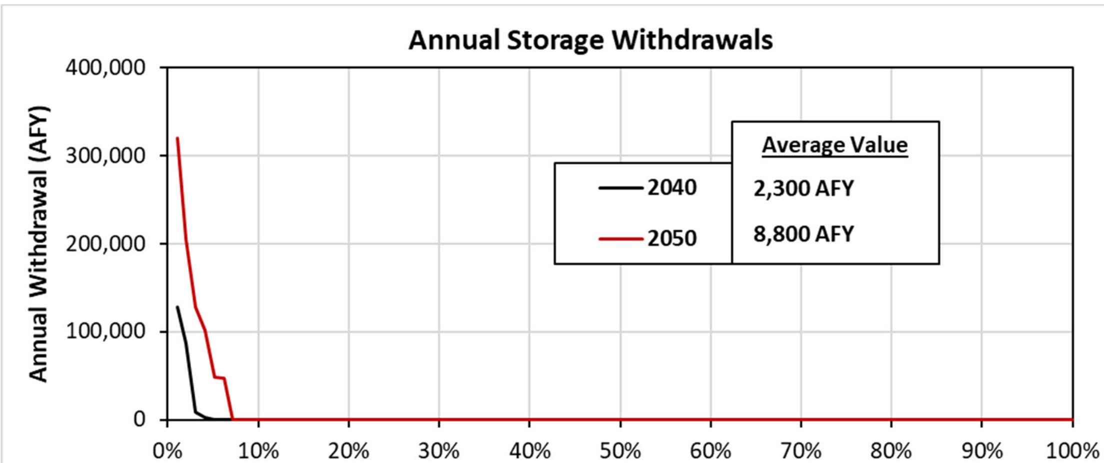


Figure 4B. Storage Withdrawals for Scenario 4

For Scenario 4, maximum reservoir withdrawals never exceed 130,000 AFY in 2040 and 310,000 AFY in 2050. The average reservoir withdrawals (across all hydrologic conditions) are 2,300 AFY in 2040 and 8,800 AFY in 2050.

The use of the new MET reservoir in Scenario 4 is almost always constrained by not having adequate storage when droughts occur, as a result of not having the Delta Conveyance implemented. This is due to the fact that without Delta Conveyance, water availability for storage is constrained in wet and normal hydrologic years. Despite the higher probability of needing additional water supply, a new reservoir is not very beneficial as the probability of not having available water to store is fairly high in Scenario 4.

Scenario 5 – No MET Carson IPR or Delta Conveyance Implemented, with Significant Climate Change

Figure 5A presents the probability of ending-period storage for the new reservoir for Scenario 3. This is a function of how much surplus water supply is available after meeting MET water demands and the filling of existing MET storage (reservoir and groundwater).

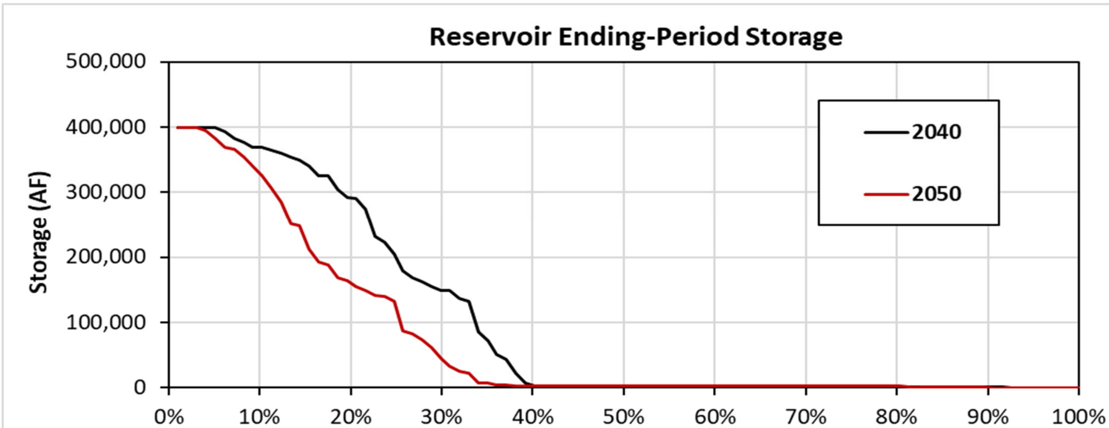


Figure 5A. Ending Period Storage for Scenario 5

In year 2040 for Scenario 5, it is estimated that the new reservoir would be at full storage volume approximately 5% of the time; while in year 2050 the new reservoir would be at full storage volume approximately 3% of the time. In 2040, it is estimated that the reservoir would be empty approximately 60% of the time; while in 2050 the reservoir would be empty approximately 65% of the time.

Figure 5B presents the probability of annual storage withdrawals for Scenario 5, which represents supply yield for the reservoir. This is a function of how much water is stored in the reservoir and the probability that there is an additional need for new MET supply.

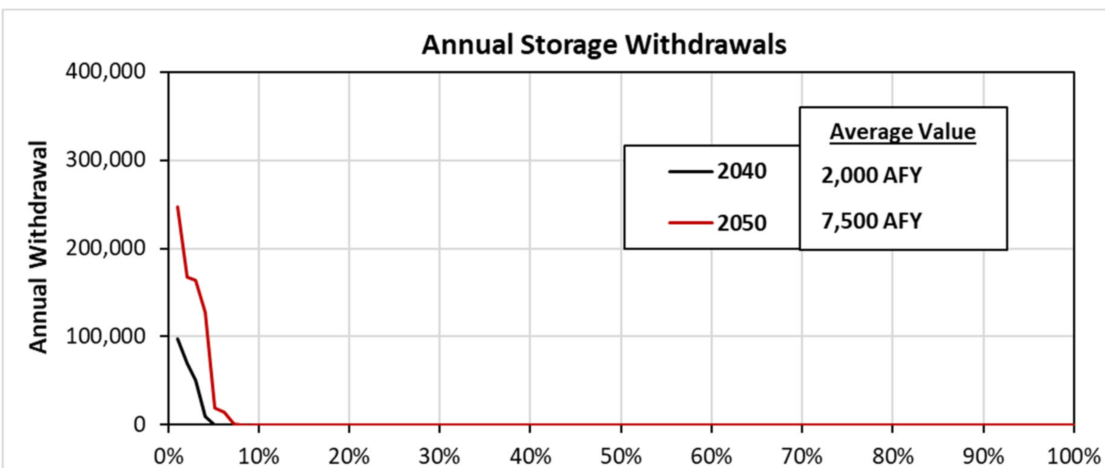


Figure 5B. Storage Withdrawals for Scenario 5

For Scenario 5, maximum reservoir withdrawals never exceed 99,000 AFY in 2040 and 250,000 AFY in 2050. The average reservoir withdrawals (across all hydrologic conditions) are 2,000 AFY in 2040 and 7,500 AFY in 2050.

The use of the new MET reservoir in Scenario 5 is always constrained by not having adequate storage when droughts occur, as a result of not having both the Carson IPR and Delta Conveyance implemented. This is due to the fact that without the Delta Conveyance

water availability for storage is constrained in wet and normal hydrologic year, and without the Carson IPR project water needs are greatest under this scenario. Therefore, Scenario 5 represents the greatest need for new water supply, but at the same time represents the worst condition for availability of water to store—making this scenario the second worst in terms of needing new storage.

Cost-Effectiveness of New MET Reservoir

Based on the estimated capital and O&M costs for the new MET reservoir and the probability of supply yield (i.e., annual reservoir withdrawals), a current year unit cost can be estimated. Current year dollars do not include future escalation or discounting. To estimate the current year unit cost, the capital cost of $3.3 billion was amortized assuming a finance rate of 3.6% over 30 years. The capital cost was developed by MWDOC by escalating the cost of DVL to 2018 dollars, dividing the cost by half to arrive at storage for 400,000 AF and then assuming the cost would be about double to account for the difficulties of finding a site with all of the attributes of DVL. Actual reservoir costs will vary considerably depending on the site-specific situation, so this assumption may be the weakest of the analysis. This assumption results in an annualized capital cost of $182 million. When the estimated O&M cost of $19.8 million per year is added, the total estimated annual cost in current dollars is $201 million. **Table 3** presents the average annual supply yield and estimated unit cost for the four modeling scenarios. Note that the unit cost presented in Table 3 does not include water treatment.

Table 3. Unit Cost of New MET Reservoir

Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Average Supply in 2040 (AFY)	500	9,800	13,400	2,300	2,000
Average Supply in 2050 (AFY)	1,400	18,100	25,850	8,800	7,500
Max Withdrawal in 2040 (AFY)	50,000	280,000	250,000	130,000	99,000
Max Withdrawal in 2050 (AFY)	130,000	310,000	400,000	310,000	250,000
Unit Cost in 2040 ($/AF)	$403,000	$21,000	$15,000	$88,000	$101,000
Unit cost in 2050 ($/AF)	$144,000	$11,000	$7,800	$23,000	$27,000

Note that a one-time withdrawal of 200,000 AF to 400,000 AF averaged over a 30-year period would result in an average yield of 6,700 AF per year to 13,300 AF per year

Conclusions

The results of this analysis indicate that a new MET reservoir with a storage volume of 400,000 acre-feet is not cost-feasible. Even under the best modeling scenario (Scenario 3) in which the need for new MET water supply was coupled with available surplus water most of the time, the average marginal supply benefit would be in the neighborhood of 26,000 AFY by year 2050. Under this scenario, the unit cost would be $7,800/AF, about 11 times the current MET untreated water rate.

Sensitivity Analyses

Re-Prioritization of Operations for New 400,000 Reservoir

If this new reservoir was re-prioritized in operations to be first in terms of filling and first in terms of withdrawals under the most favorable conditions, as depicted in modeling Scenario 3, the average supply yield would be approximately 40,000 AFY in 2040 and 76,000 AFY in 2050. This would result in a unit cost of $5,000/AF in 2040 and $2,600/AF in 2050—still significantly greater than other options available to the region and Orange County, including seawater desalination. However, re-prioritization of the new reservoir operations would diminish the economic value of MET's current reservoir storage and groundwater banking programs. As such, the economic evaluation for this sensitivity would come under scrutiny by MET and others.

Smaller Reservoir

A reader of the evaluation may comment that the analysis was skewed because the reservoir size specification of 400,000 AF was made too large and that a smaller reservoir may be more cost-effective. Using the best-case modeling scenario for the need for additional storage (Scenario 3), a 200,000 AF reservoir was evaluated. Under this sensitivity, the annual cost of the reservoir in current year dollars is $100 million. The average annual supply yield of this smaller reservoir is estimated to be 13,000 AFY in 2040 and 21,000 AFY in 2050. Thus, the current year unit cost would be $7,700/AF in 2040 and $4,900/AF in 2050, assuming MET's current reservoirs are prioritized in operations. While these unit costs are significantly improved over the unit costs of the 400,000 AF reservoir presented in Table 3, they would still represent costs that are significantly greater than MET's current untreated water rate and other supply options available to Orange County, including seawater desalination.

Further Reading on Storage in California

California WaterBlog

A biologist, economist, engineer and geologist walk onto a bar…

Expanding water storage capacity in California

Posted on February 22, 2012 by Elena M. Lopez

Jay R. Lund, The Ray B. Krone Chair of Environmental Engineering, University of California – Davis

Shasta Dam retains water to form Shasta Lake reservoir. (Photo: US Bureau of Reclamation, http://www.usbr.gov/mp/ncao/shasta/virtual_tour.pdf)

"The old gray mare, she ain't what she used to be."

The recent report from the US Bureau of Reclamation on the economic feasibility of raising Shasta Dam illustrates that we are in a new era for considering water infrastructure management in California.

This study, perhaps a decade or more in the making and costing millions of dollars, examined the economic feasibility of expanding a single facility (Shasta Dam) which is a modest part of a very large, complex, and changing water system serving many purposes.

Some observations:

1. The study found that the most economical expansion was about 14% (634,000 acre-ft), costing $1.1 billion dollars, roughly $1,700 per acre-ft of storage capacity. This would expand statewide surface storage capacity by 1.5%, although water storage capacity is **not** equal to water deliveries.
2. This expansion produces an additional 76,000 acre-ft of firm yield (dry year deliveries). This is less than 0.2% of agricultural and urban water use in California. (Modern water engineers will wonder why the antiquated *firm yield* is still the main water supply indicator.) Average annual deliveries increase by only 63,000 acre-ft. Other traditional benefits (hydropower, recreation, flood reduction) were small.
3. Most water supply benefits are for users south of the Sacramento-San Joaquin Delta, implying that Delta export capability is needed to deliver this amount of water. If the Delta doesn't work, then this surface storage expansion for water supply doesn't work.
4. More than half of the estimated economic benefits are from expansion of the cold water pool needed to support cold water habitat for winter run Chinook salmon, valuing salmon smolt at $50 each. Ironically,

winter run Chinook salmon need cold water below Shasta Dam because Shasta Dam prevents salmon from reaching the cold water streams where they naturally spawned and reared.

5. Because fish benefits are most of the project's benefits, the report proposes that the public pay for these benefits, approximately $654 million or $31 million/year. Essentially, the fish benefits buy back some of the cold water lost when Shasta Dam was built in 1944. If we had $654 million for winter run salmon recovery, would this be the best investment for these fish? This more relevant question is not asked.

Aerial view of Shasta Dam. (Photo: Wikimedia Commons, http://en.wikipedia.org/wiki/File:Aerial_view_-_Shasta_Dam_CA.jpg)

Some conclusions:

1. New major water projects are increasingly justified based on recovering fish and environmental benefits lost through construction of previous projects. Yet we are not seriously studying what would be the best investment portfolio for fish and the environment. We are still trying to justify individual projects rather than trying to find the best portfolio of activities to accomplish objectives, particularly environmental objectives. This approach is backwards, and ineffective.
2. Independent single-facility studies of improvements to a complex system are expensive and time-consuming, and distract us from addressing greater system-wide problems. If we continue to study this complex system incrementally, money and time will be spent without substantial improvements or strategic direction.
3. California's water system increasingly functions with integrated, diverse, and often geographically decentralized portfolios of actions. Most major water agencies employ a mix of traditional water supply actions, water conservation actions, conjunctive use of ground and surface water, and water market or transfer agreements. We cannot capture or take advantage of these complexities with single-project studies. Indeed, single-project studies for the main system can be misleading.
4. California's state and federal water agencies are not well equipped technically to do system studies to identify promising improvements in infrastructure for such complex systems with many interacting parts and objectives.
5. It has never been easy to conduct systematic analysis of water management opportunities in California. Only at times of desperation or unusual reflection has this been possible (Pisani 1984; Kelley 1989). Such studies always have controversial and thought-provoking conclusions.

Overall, California's water system functions in ways fundamentally different from how the major state and federal agencies conceive their major water supply system and planning investigations. This causes many state and federal planning studies to be ineffective, costly, prolonged, and distracting of public attention, rather than insightful and useful. At the local level, many water districts and agencies are doing a far better job of developing integrated portfolios of diverse and often decentralized actions to satisfy multiple objectives. Similar, but more difficult, analysis at state and regional levels will provide thought-provoking insights for both water and environmental management.

Further Reading

Hanak, E., J. Lund, A. Dinar, B. Gray, R. Howitt, J. Mount, P. Moyle, and B. Thompson, *Managing California's Water: From Conflict to Reconciliation*, Public Policy Institute of California, San Francisco, CA, 500 pp., February 2011.

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Water Storage in California

Posted on September 13, 2011 by cathrynlawrence

Jay R. Lund, The Ray B. Krone Chair of Environmental Engineering, University of California – Davis

> *"With a larger reservoir, there is some increasing gain with further size, but in a diminishing ratio." – Alan Hazen (1914)*

Lake Shasta, March 2009 (CA Department of Water Resources)

Water storage capacity is an important tool in California's water system for capturing lower-value water for higher-value uses later. Such storage aids water supply, flood protection, hydropower, and recreational uses and helps regulate downstream water quality and supply cold water flows for fish. California has about 42 million acre-feet(maf) of surface reservoir storage capacity and much more storage capacity in underground aquifers (150 million to 1.45 billion acre-feet, depending on how you count it).

- *Seasonal water storage:* In normal years, about 8-14 million acre-ft of water is stored in the wet season and used in the dry season. This compares to roughly 34 maf/yr of average net agricultural and urban water use. Human water use is highest in California's dry summer, so crops and landscapes must be watered from stored winter and spring flows. Roughly 5-8 maf is held in surface reservoirs and 3-6 maf is held in groundwater basins.
- *Drought water storage:* Water also is stored from wet years for use in dry years. The amount stored varies with the drought's intensity and length. Stored surface water is mostly used in the initial drought years, while stored groundwater plays a larger role in prolonged droughts. I'm unaware of anyone with data on statewide drought storage use, but from our modeling results, about 35-43 maf is ideally carried over from wet to dry

years for droughts lasting 3-6 years. Of this total, some 15-18 maf is held in surface reservoirs and 20-25 maf in aquifers.

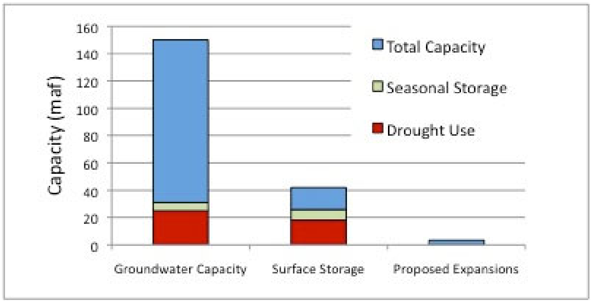

Figure 1: Statewide capacities and approximate use of surface and groundwater storage, and proposed surface storage expansion.

- *Should we pay for more water storage?* All combined, proposed state expansions of surface storage facilities would add less than 3.3 maf of new capacity (Sites: 1.3-1.8 maf, Temperance Flat: 0.43-1.3 maf, Los Vaqueros: 60-175 taf). This is not much relative to existing capacities (Figure 1). In evaluating cost and effectiveness of such facilities, size, connections, and location matter, among other things.
  - *Storage effectiveness decreases with size:* Reservoirs only store water, they cannot create it. No reservoir can reliably deliver more than the reservoir's average annual inflow (minus evaporation). Enlarging a reservoir always increases water deliveries by a smaller proportion (Hazen 1914). Similarly for flood management, larger reservoirs provide more control, but with decreasing incremental effectiveness. Most easy, cheap, and effective reservoir locations in California already have reservoirs.
  - *Flexibility varies with storage type:* Traditional surface reservoirs (on-stream storage behind a dammed river) fill directly with stream flow, and can empty as fast as gravity and its outlet structure allow. Today most new surface storage is off-stream storage (e.g. Sites, Los Vaqueros), which fills more slowly with pumps, increasing costs and reducing its ability to manage floods. Groundwater storage usually fills slowly by infiltration from the surface, making aquifers less directly useful for managing floods. Groundwater also must be pumped out, also at a limited pace and at some cost. Such limitations on filling and withdrawing water from storage are important considerations for system operation and performance.
  - *Location, location, location:* The value of storage depends on its location in a network. Storage is most valuable when releases can be brought to use. If Delta conveyance is "broken", north of Delta storage (e.g., Sites reservoir) becomes less valuable.

Lake Oroville Dam, February 2009. Note the distance of the water from the spill way gates (middle right).

Lake Oroville spillway, 1997 (Rand Schaal)

- *Storage should be examined and used as part of a system*. Thinking about new storage investments should consider the following factors.
  - *Storage investments should be a business decision*. Water managers will always prefer more storage capacity, especially if it is free. But surface storage has substantial costs (financial, environmental, legal), and political controversy. Is more storage at a particular location a good system investment, relative to other uses of scarce money (and political attention)?
  - *Storage has somewhat different roles from the past*. Water markets, water conservation, water reuse, conjunctive use of ground and surface waters, and other innovations change how we can best use storage assets. Water demands also have grown and become more diverse. Water markets and conjunctive use, in particular, increase the value of coordinated operation. Expanding storage will be less effective without other, perhaps greater, changes in water use and

management.

- *Better management can improve the value of storage.* Coordinated operation of storage and other water management activities can improve overall performance by making more effective use of existing or new storage. In the 1970s, vast expansions of storage were proposed on the Potomac River to supply the Washington, DC area. A university reoperation study found that adding only one small reservoir would enable existing reservoirs to handle expected growth in demands (Palmer et al. 1982). Increases in conjunctive management of water surface and groundwater storage in California since the 1980s have already greatly improved system performance. There remains potential for improvement.
- *Climate change might affect the value of storage.* Climate warming is reducing the ability of California's snowpack to store water seasonally. Fortunately, downstream reservoirs on many streams are already large compared to seasonal changes in streamflows and flood peaks. Model results show that with the right management, climate warming might be inconvenient, not catastrophic, for most water uses.
- *Warming will likely bring difficulties in managing stream temperatures for salmon.* Larger reservoirs or changed operations might better preserve cold water for fish. Reduced precipitation could pose great challenges for water supplies and ecosystems. But larger reservoirs might not be of much help; with a much drier climate, there could be too little water to fill even existing storage capacity.
- *Some places seem more promising for new storage than others.* From modeling work and observations, additional storage seems most promising at or above Folsom reservoir (for floods, perhaps as a dry dam), Los Vaqueros (for improving delivered water quality), Kaweah and Tule river storage mostly (to reduce operating costs), and improved groundwater recharge and storage in metropolitan areas, the Sacramento Valley, and elsewhere. Other places might prove promising, especially if investments and management are coordinated systemwide for several human and environmental purposes. A system-wide business case is needed for such large investments. Few expansion proposals will pass this test.
- *Most storage expansion costs must be borne locally.* Federal and state budget problems mean that most future water infrastructure will need to be financed by local beneficiaries. Even if the currently proposed water bond is passed, less than 50% of storage costs could be covered by state general revenues. This places local agencies and users in the driver's seat, and seems to render most state discussions moot until local contributors become apparent. However, infrastructure of statewide importance is unlikely to emerge without an ability of local agencies to trust in state or regional planning, policy, and contracting efforts.

Water storage is important for most human and environmental objectives, but has large costs and must fit within a large and diverse water and environmental system. We should be thoughtful and creative in thinking about storage or other major investments, and ultimately cold and calculating about their value.

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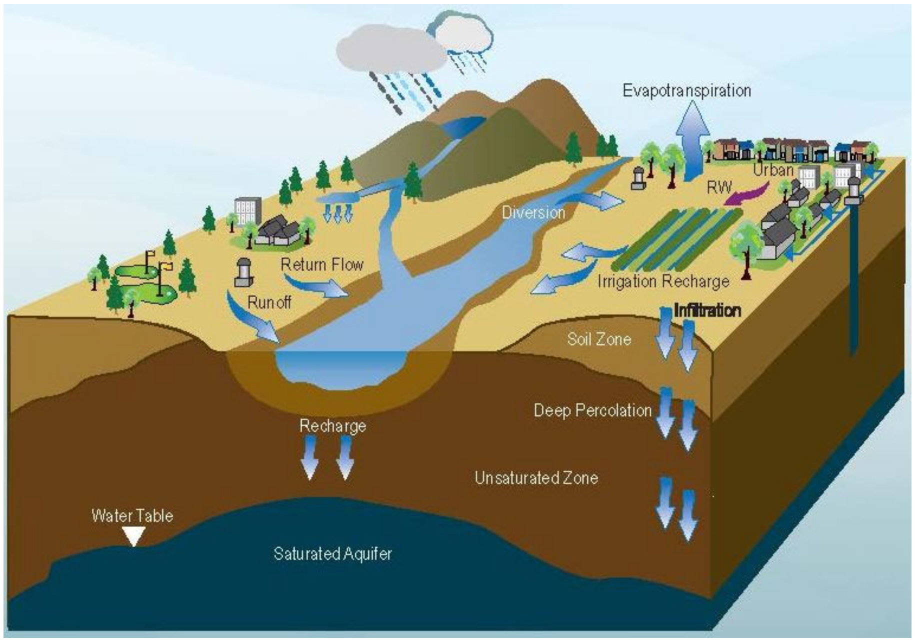
Shaping water storage in California

Posted on November 20, 2014 by UC Davis Center for Watershed Sciences



From cover of new report, "Integrating Storage in California's Changing Water System"

By Jay Lund, Maurice Hall and Anthony Saracino

With the continuation of California's historic drought and the recent passage of Proposition 1, the potential value of additional water storage in the state is an area of vigorous discussion.

In a new study released today, we look at the different roles of storage in California's integrated water system and evaluate storage capacity expansion from what we call a "system analysis approach." This approach emphasizes how new storage projects, both above and below ground, can work in combination with one another and in concert with the broader water management system.

Surface water reservoirs provide benefits by capturing water when it is more abundant and storing it for times of greater water scarcity (most commonly storing water from California's wet winter for its dry spring and summer, but also providing some ability to save water for short droughts). Groundwater in California provides larger capacity storage for the longer term, such as for multi-year droughts, and is a substantial source of water and seasonal storage in places where surface water is limited.

In California's vast and interconnected water system, storage projects should not be evaluated in isolation. Instead, storage should be considered and analyzed as part of larger portfolios of infrastructure and management actions, including: various water sources; various types and locations of surface and groundwater storage; various conveyance alternatives; and managing all forms of water demands. Such an integrated, multi-benefit perspective and analysis would be more valuable and would be a fundamental departure from most ongoing policy discussions and recent storage project analyses.

Our study and earlier work shows that the ability to utilize additional water storage in California is finite and varies greatly with its location, the availability of water conveyance capacity, and how the system is operated to integrate surface and groundwater storage, conveyance and water demands.

At most, California's large-scale water system could potentially utilize between 5 and 6 million acre-feet of additional surface and groundwater storage capacity, and probably no more. The limitation stems primarily from a lack of streamflow to reliably fill larger amounts of storage space.

Major water storage expansion proposals

Proposal	Region	Owner/ Proponent and Description	Capacity, taf
Surface Storage Programs			
Shasta Lake Enlargement	Sacramento	Reclamation/DWR - On-Stream Storage to increase regulating capabilities and yield opportunities	Up to 640
Sites Reservoir	Sacramento Valley	DWR/Reclamation/Sites JPA - Off-Stream Storage for local and system-wide yield opportunities	1,200 to 1,900
In-Delta Storage	Sac. -San Joaquin Delta	Island Storage in Central or Southern Delta for Delta flows or exports	230
Los Vaqueros Enlargement	Delta	Reclamation/CCWD - Water supply storage off California Aqueduct or Delta-Mendota Canal	Up to 965
Millerton Lake Enlargement	San Joaquin River	Reclamation/DWR - On-Stream Storage to increase flow regulating opportunities	720
San Luis Enlargement	San Joaquin Valley	Reclamation/DWR - Increased off-stream storage for improved CVP and SWP deliveries	370
Groundwater Storage Programs			
Sacramento Valley Region	Sacramento Valley	Local entities - Local and regional groundwater banking for water supply and the environment.	Up to 3,500
San Joaquin Basin	San Joaquin Basin	Local Entities - Madera Ranch and similar groundwater banking opportunities for water supply storage.	Up to 2,500
Tulare Basin	Tulare Basin	Local Entities - Kern and Semitropic water banks successfully operate, and other groundwater banking are being investigated.	Up to 12,000
Other local and regional Storage opportunities	Southern California, Central and South Coast	Local and Regional Entities - Various local and regional groundwater storage programs	Up to 4,000

Source: Integrating Storage in California's Changing Water System, 2014

In the long term, this limitation is likely to tighten with a drier climate, though it can loosen somewhat with wetter and more variable streamflows.

The most promising new storage projects would provide annual water deliveries of 5-15 percent of the new storage capacity. Said another way, a storage project with 1 million acre-feet of storage capacity would likely provide an average of only 50,000 to 150,000 acre-feet of new supply a year.

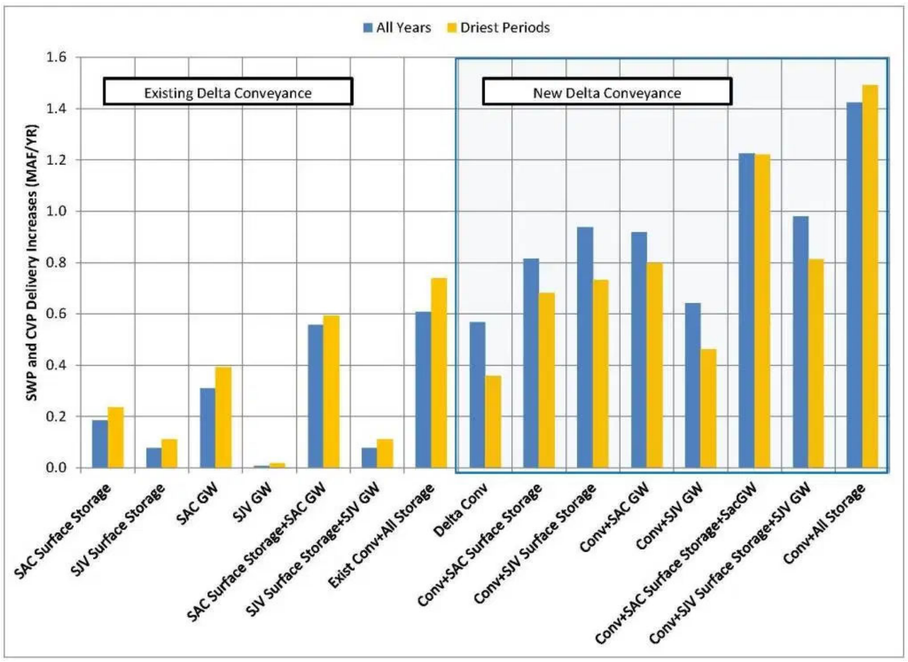
Our study also demonstrates that the water supply and environmental performance of additional storage capacity are greatest when surface and groundwater storage operations are integrated and coordinated. The benefits and likely cost-effectiveness of coordinating surface and groundwater storage and conveyance operations greatly surpass the benefits of expanding storage capacity alone. Integrated operation can expand annual water delivery to as much as 20 percent of the increase in storage capacity.

This does not necessarily mean that the benefits of expanding surface or groundwater storage capacity exceed their substantial costs; we did not delve into benefit and cost calculations. But there is enough water and water demand to take advantage of up to about 5 or 6 million acre-feet of additional surface and groundwater storage within the Central Valley, were this capacity available and in the right places.

This new storage volume would increase California's total water supply by at most 5 percent and, if targeted appropriately, could provide more reliable supplies for farms and cities as well as more flows at the right time and place for fish and wildlife.

However, expanding water storage is no panacea by itself; it must be combined with other system improvements and actions in an integrated portfolio approach to California's water system.

Integrated water management and Delta water deliveries



More integrated water management greatly increases water deliveries. This graph shows average delivery increases for various Delta conveyance assumptions and combinations of four surface and groundwater storage expansions in the Sacramento and San Joaquin valleys. *Sources: Historical climate data, CalLite water model (described in appendix of storage study)*

More integrated water management greatly increases Delta water deliveries. This graph shows average water delivery increases for various Delta conveyance assumptions and combinations of four surface and groundwater storage capacity expansions in the Sacramento and San Joaquin valleys. Sources: Historical climate data and the CalLite water model described in appendix of storage study

Water infrastructure programs purposely designed and implemented to work with other parts of the water system and other water management actions can significantly outperform individual projects in achieving objectives for water supply, healthy ecosystems and flood protection — under a variety of climate conditions (Harou et al. 2010; Connell-Buck et al. 2011; Ragatz 2013).

Studies examining water storage and water management generally should explicitly consider the potential for integrating surface and groundwater storage, as well as conveyance and water demand management for water supply, ecosystems and flood protection. Recent state groundwater legislation could be instrumental in supporting such coordination regionally and locally.

The benefits of integrated management are clear. A transformation is needed in how agencies and stakeholders think about conducting water infrastructure studies if California is going to squeeze the most benefit from our water infrastructure investments, including the Prop. 1 funds.

Jay Lund is director of the UC Davis Center for Watershed Sciences. Maurice Hall is California water science and engineering lead for The Nature Conservancy and Anthony Saracino is a water resources consultant in Sacramento.

Jay Lund talks about water storage study

droughtwatch

California water: Can't store what you don't have

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Further reading

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Travis *says:*
November 20, 2014 at 11:17 am

Nice article. "The limitation stems primarily from a lack of streamflow to reliably fill larger amounts of storage space" Reliability is not necessary, but when we do have very wet years, it would be nice to store that water. .
Also is the science settled (more or less) that California's future bodes for a drier climate? Until recently, I had thought we were to expect less snowfall, but overall more precipitation.

★ Like
Reply

Douglas Deitch *says:*
November 20, 2014 at 11:39 am

As we all know, our natural systems such as particularly our ground water aquifers, provide the best opportunities for California water storage. Just eliminating chronic overdraft and water mining of critically important food production related water commons to stop the bleeding and commence living within the sustainable agricultural carrying capacity would be a major victory and is a more than obvious place to start.

Monterey Bay Conservancy has been continuously proposing such a water project in the Monterey Bay/Pajaro Valley-PVWMA Region since 1998 (http://www.pogonip.org/solution.html , http://www.pogonip.org/WaterDocs/98USGSTechnicalMemorandum.pdf , http://www.begentlewiththeearth.net , http://www.begentlewiththeearth.org) to correct the decades long massive ag overdrafting and water mining in this area which has actually increased by over 27% over the last few growing seasons in response to this record drought, with no production reductions at all.

With the passage of the $7.5 million water bond, around $400,000,000 is now available to implement a shovel ready (but no shovel even required) immediate and 100% sure fire in perpetuity 24,000 acre foot per year water conservation project which will terminate all future salt water intrusion in this area, provide sustainable local ground water for all users, protect in perpetuity some of this country's most rare and critical habitats and farmlands, improve coastal access, improve and diversity the local economy and protect food production, and publicly acquire and fallow, for around $50,000 per acre … http://www.santacruzsentinel.com/general-news/20140227/retired-federal-judge-buys-borina-farmland-in-major-pajaro-valley-deal … the around 8000 plus acres of irrigated farmlands, 25% of Pajaro Valley's total, on the ocean side of Highway One from La Selva Beach, in Santa Cruz County, to Elkhorn Slough in Monterey County.

I submit there is no better utilization of around 5% of this bond's funding in the State of California …

https://civinomics.com/initiative/4WBI/living-within-our-natural-water-means-in-santa-cruz

Douglas Deitch
ED/MBC
Santa Cruz, Ca.
http://www.dougdeitch.com

★ Like
Reply

tsac0008 *says:*
November 20, 2014 at 3:29 pm

The Douglas Deitch comments are very appropriate and bring up the fact that our California agriculture as a whole, not just the Santa Cruz and Monterey County factions, are out of control in regards to water overuse. The type of farming allowed in an area should be tied to available supply and sustainability. Mining groundwater from one area to sell to another that is already depleting theirs is simply a rediculous and inappropriate proposal. It is well worth noting again and again that it is non-sustainable agriculture that leads the way in destruction of our natural resources and water supplies. It is the same growers that deplete water supplies that also contaminate our state's waters. Right to Farm Laws do not give the Farmers the Right to Rape the state's water supply.

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Michael Fritts *says:*
November 20, 2014 at 6:05 pm

I'm GOING TO KEEP ON THIS UNTIL SOMEONE GETS IT. A NATIONAL FREAH WATER PIPELINE THRU EVERY STATE. WANT TO HEAR MORE TO THIS CONTACT ME. PLEASE.

★ Like
Reply

Douglas Deitch *says:*
November 20, 2014 at 8:57 pm

Concur 100%.

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INTEGRATING STORAGE
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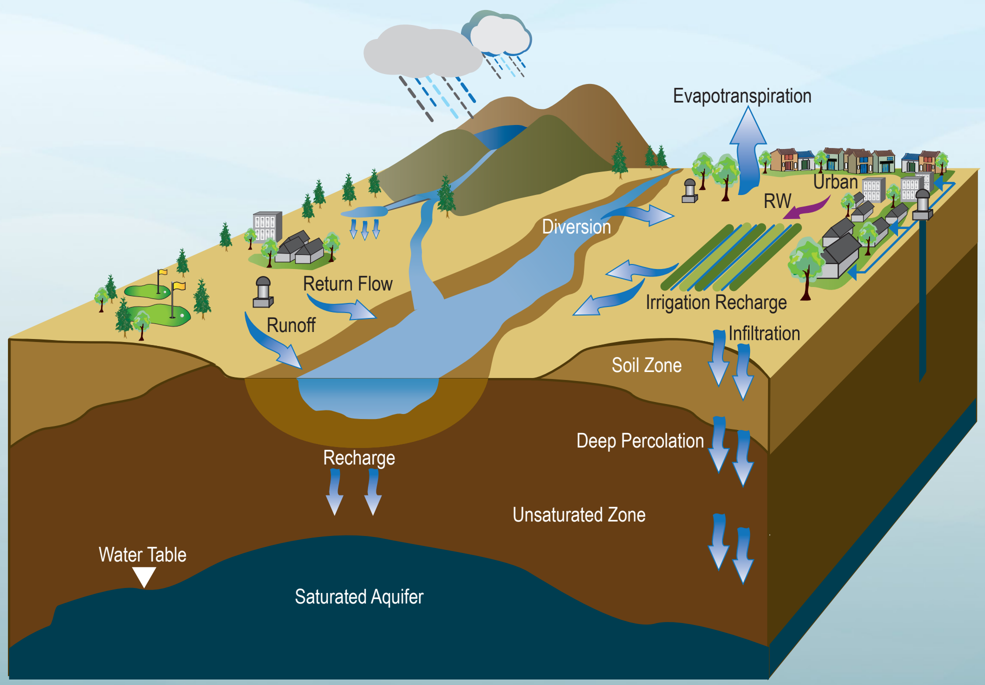

Jay Lund, University of California at Davis
Armin Munévar, CH2M HILL
Ali Taghavi, RMC Water and Environment
Maurice Hall, The Nature Conservancy
Anthony Saracino, Water Resources Consultant

With contributions from:
Leo Winternitz, formerly of The Nature Conservancy, and
Jeffrey Mount, Professor Emeritus, University of California at Davis

November 2014

This effort was supported with funding from the S.D. Bechtel, Jr. Foundation
URL: https://watershed.ucdavis.edu/library/integrating-storage-californias-changing-water-system

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Integrating Storage in California's Changing Water System

Jay Lund, University of California at Davis
Armin Munévar, CH2M HILL
Ali Taghavi, RMC Water and Environment
Maurice Hall, The Nature Conservancy
Anthony Saracino, Water Resources Consultant

November 2014

Summary

Surface water reservoirs provide water supply and flood management benefits by capturing water when available and storing it for use when needed. Surface reservoirs are commonly operated more for seasonal or short-term inter-annual needs. Groundwater aquifers generally provide longer-term storage and a source of water and seasonal storage in areas where surface water is limited. This paper reviews the benefits and challenges of water storage in California's evolving water system, and provides some quantitative insights from an integrated analysis of this system.

Water storage should not be viewed as isolated projects. For today's water management objectives and conditions, surface water and groundwater storage should be considered and analyzed as parts of larger systems or portfolios of actions that include a wide variety of water sources, types and locations of storage, conveyance alternatives, and managing all forms of water demands. Such an integrated, multi-benefit perspective and analysis is a fundamental departure from most ongoing policy discussions and project analyses.

The pilot study described in this paper focused on water storage and concludes that ability to utilize additional water storage in California varies greatly with its location, the availability of water conveyance capacity, and operation of the system to integrate surface, groundwater, and conveyance facilities.

At most, California's large-scale water system could utilize up to 5-6 million acre-feet of additional surface and groundwater storage capacity, and probably no more, which would likely provide 50-150 taf/year of additional water delivery for each million acre foot of additional storage capacity alone. The water supply and environmental performance of additional storage capacity is greatest when surface and groundwater storage are operated together. The benefits, and likely cost-effectiveness, of coordinating surface and groundwater storage and conveyance operations greatly surpass the benefits of expanding storage capacity alone, greatly expanding water delivery increases to as much as 200 taf/maf of additional storage capacity.

Because we did not quantify and compare the economic value and costs of water supply and other benefits of expanding storage capacity, we cannot yet say if particular expansions would be economically justified. Similarly, because we did not comprehensively analyze the environmental impacts of expanding storage capacity or specific storage projects, we cannot yet say if particular expansions would be environmentally justified. Further, this study does not consider reoperation of existing facilities, water demand management, changes in prioritization of water uses or rights, or other policy or regulatory actions that might change the ability to supply water demands using existing water storage capabilities.

Introduction

California is a semi-arid state with tremendous variability in water conditions and demands. Water is relatively abundant in the northern and mountain regions in the wet winter and very scarce in the major agricultural and urban areas during the dry spring, summer, and fall. California's current drought is not unique. Over the last century, California has seen droughts up to six years long, as well as occasional severe floods. In the more distant past, more severe droughts have occurred, some lasting many decades, as well as numerous intense and large-scale floods (Kleppe et al. 2011). California's current drought is in its third year, and could last several more years. Surface water and groundwater storage are being discussed prominently in the context of this drought. Water storage in California is fundamental to managing variability in water supply for human purposes, but has fundamentally harmed many of the state's native habitats and species, which evolved in a naturally variable environment. Californians often hold conflicting views on water storage capacity and its expansion, a debate that will be prominent as the California Water Commission makes decisions on investments for public benefits associated with storage projects, as approved by California voters on the November 2014 ballot and as other storage opportunities and issues arise.

This paper begins with some background on California water storage development and challenges, followed by a discussion of how water storage works to address these challenges and the limitations of current storage capabilities. The paper then describes the advantages of a new approach to water storage investigation, an approach that considers storage and other actions in the context of a more integrated system. Lastly, the proposed new approach for evaluating the role of water storage in California is explored through a pilot study. The results from this study suggest some important directions for evaluations of water storage expansion in California and provide some technical and policy insights for moving forward.

Background

California water development has always been an evolving process of re-aligning infrastructure and operations to changing water demands and conditions (Hanak et al. 2011). This section reviews California water management from the perspective of the evolving purposes for which water is managed, and how this has affected the development and use of water stored in surface reservoirs and groundwater. The section concludes with a discussion of today's major storage questions and issues. Addressing today's issues will require new thinking and analytical approaches that treat storage as one integral component of California's complex water management infrastructure.

Table 1 summarizes the major purposes of California's water management system and the roles of surface reservoir and groundwater storage in serving these purposes.

Table 1. Surface and Groundwater Storage Serves Many Purposes in California

Purpose	Roles of Storage	Performance Indicators
Water supply delivery	Seasonal and short-term storage in surface reservoirs and groundwater; Annual and long-term storage mostly in groundwater	Local and regional water deliveries, South of Delta and Bay Area deliveries (for major Central Valley reservoirs), Economic production from deliveries (or economic losses from un-met deliveries)
Flood Management	Storage of flood peaks in surface reservoirs	Average annual flood damage (or avoided damage), Flood stage reduction
Energy production	Seasonal and peaking energy storage; Energy production from streamflow	Hydropower revenues; Kilowatt-hours generated
Water Quality	Reservoir flow regulation of temperature, contaminants, and Delta salinity; aquifer disposal of contaminants	Temperature, salinity, and other water quality metrics
Ecosystem support	Dams interrupt habitat and alter flow patterns; Reservoirs provide cold water downstream and regulate environmental flows; Groundwater supports overlying wetlands and riparian corridors	Temperature targets; Area of habitat type provided; Meeting prescribed salinity, temperature, depth, flooding pattern requirements; Delta flow patterns; San Joaquin river flow patterns; Fish production/populations
Recreation	Lakes and regulated streamflow for boating, fishing, and aesthetics	Recreation days, Recreation revenues, Quality of life indicators

Surface Storage Development

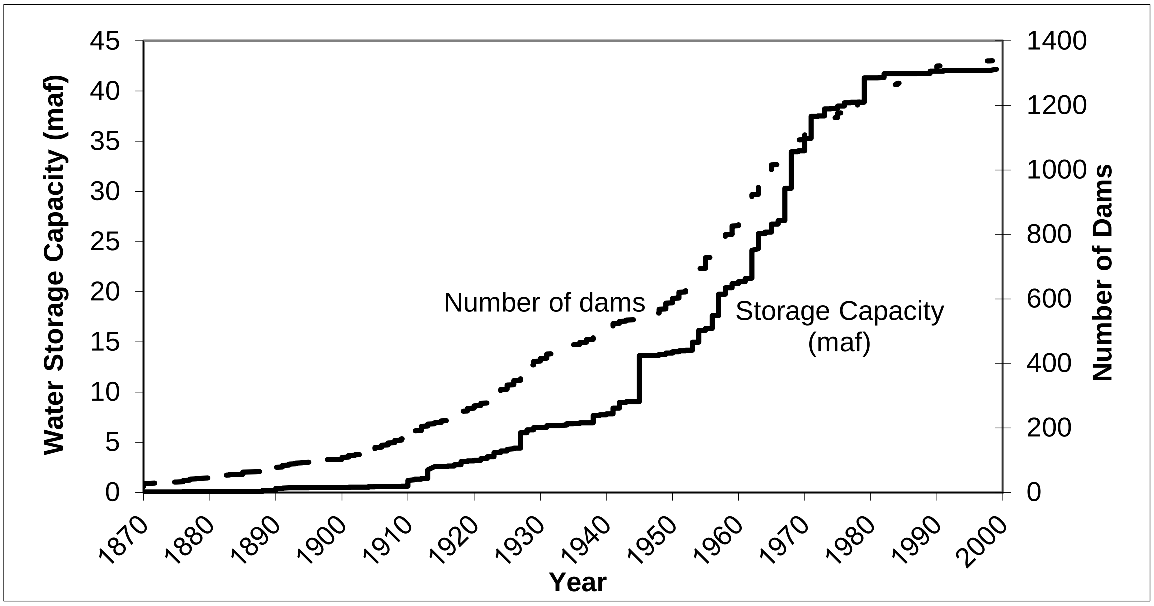
Figure 1 shows the growth in the number and total storage capacity of dams in California since the late 1800s. The earliest dams in California, built in the late 1800s and very early 1900s, only diverted water for hydropower, local irrigation, and drinking water supplies and usually had little storage capacity. Nevertheless, these dams disrupted fish migrations and reduced downstream flows. Between 1900 and 1920, increasing diversions for local irrigation greatly depleted Sacramento River and San Joaquin River inflows to the Sacramento-San Joaquin Delta (Delta) during the irrigation season, causing the City of Antioch to move its intake eastward and considerable salinity intrusion into the Delta in dry months of dry years (Pisani 1986; Lund et al. 2010; Division of Water Resources, 1930; Hanak et al. 2011).

The first major surface water reservoirs for storage were developed further upstream, in the Owens Valley (1913) and Hetch Hetchy Valley of the Tuolumne River (1923) where larger dams were built in valleys to store significant volumes and allow diversion of the stored water from these watersheds to the distant cities of Los Angeles and San Francisco (Kahrl 1986; Hundley 2001).

The Central Valley Project (CVP) was conceived to protect the Central Valley from crippling water shortages and devastating floods. Financed by the federal government, construction of the CVP began in 1937 and now includes 20 dams, over 400 miles of conveyance facilities, and 9 million acre-feet (maf) of storage capacity. The State Water Project (SWP) was authorized by the California legislature in 1951 as a water storage and supply system to capture and store rainfall and snowmelt runoff in Northern California for delivery to areas of need throughout the

State. The SWP includes 33 reservoirs, 29 pumping or generating plants, approximately 700 miles of aqueducts and 5.8 maf of storage capacity. Including local projects, California now has approximately 1,400 regulated reservoirs, with a total storage capacity of about 42 maf. The largest 10% of these reservoirs have 95% of this capacity and the 14 largest 1% of these reservoirs have 60% of all surface storage capacity.

Figure 1. Historical Development of Surface Storage in California



Source: California Division of Safety of Dams data

Roughly 35 maf of California's surface water storage also stores energy (as well as water) and supports hydropower production with 13 gigawatts of combined turbine capacity at 343 hydropower plants, providing 5% to 15% of the state's electricity, depending on drought conditions.[1] Most hydropower plants were built between the early 1900s and 1980. Most major water supply storage reservoirs also have considerable generation capacity, albeit at lower elevations, and their hydropower operations are usually secondary to water supply and flood management.

Reservoirs also can be operated for ecosystem management. Dams have severely disrupted fish migration corridors, altered water and sediment flows, and cut off access to habitat for many native species, and overall have been a key factor in the decline of California's once abundant runs of wild salmon and steelhead, many of which are now listed as threatened or endangered under state and federal law (Moyle et al 2013). However, within this highly altered environment, dams are increasingly operated to support native species, sometimes in novel ways. For example, the endangered winter run of Chinook salmon naturally spawned and reared on the Pit and McCloud rivers, which are now inaccessible due to construction of Shasta Dam in the 1940s. Today, the winter run salmon rely on the operation of Shasta Dam to maintain water temperatures suitable for spawning and rearing downstream of that dam for their survival, at an unnatural location and elevation for winter-run salmon. Temperature control using dams is sometimes discussed as a strategy for supporting salmon populations in the face of climate

[1] http://www.energyalmanac.ca.gov/renewables/hydro/

warming. Also, dam releases now often supply water to wetlands which were more extensively supplied by seasonal flooding and groundwater prior to the extensive development of our water system. So far, most ecosystem-focused operations have been conducted and financed by dam owners under obligations to help meet state and federal endangered species and water quality requirements.

Recreation on lakes and rivers has major local economic and social benefits and moderately affects the operation of reservoirs, particularly for reservoirs that release water for river rafting. In fact, without surface reservoirs, lake and river recreation would be severely limited during California's many dry months. Wetlands, supported by reservoir releases and by groundwater, also are important for fishing and other wildlife-focused recreation, such as bird-watching.

Groundwater Development

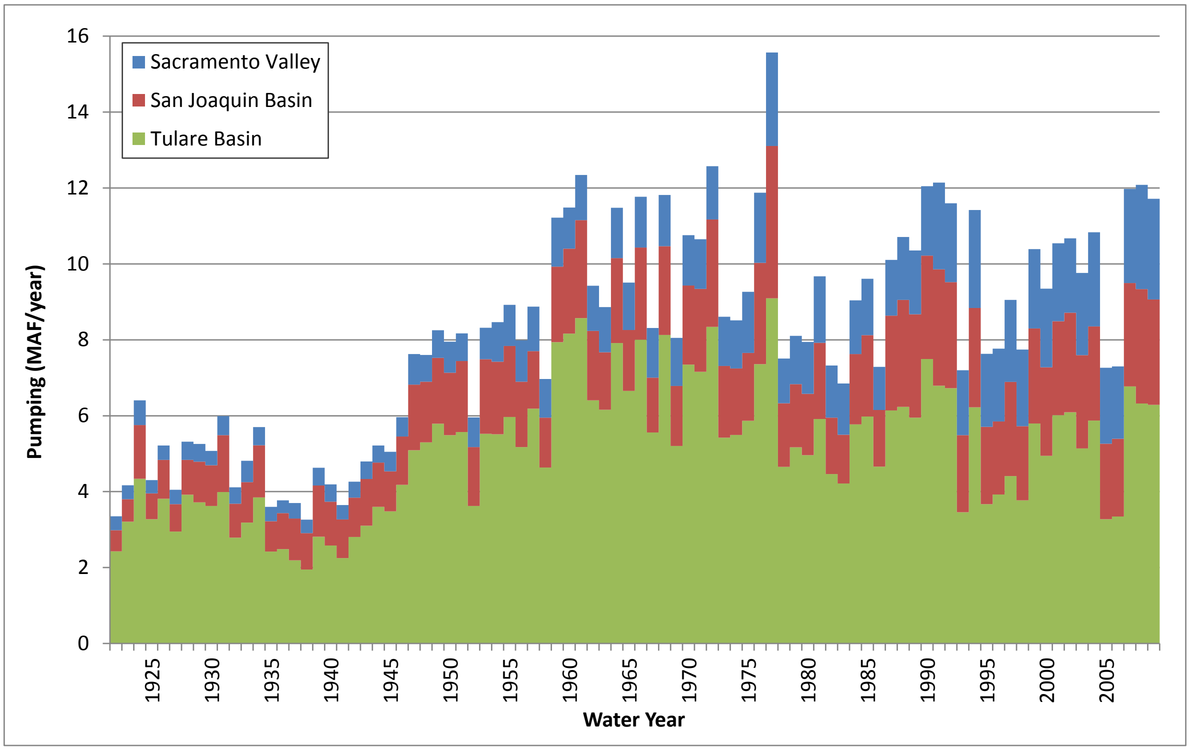
During the early period of surface storage development in California, little groundwater was used beyond shallow wells mostly for domestic supply. Later, following the development of drilling technology, aquifers were tapped in many parts of California for local irrigation. With the development of diesel and electric pumps in the 1910s to 1920s, groundwater pumping became widespread for areas lacking developed surface water supplies (Pisani 1986). By the 1930s and 1940s, groundwater was a major water supply for many areas with little or no access to surface water resources. Increasing agricultural and urban water demands caused significant reliance on groundwater resources. In average years, approximately 30-40 percent of statewide annual agricultural and urban water demand is met by groundwater, while in wet years, the groundwater usage is less, and in dry years, the groundwater can provide approximately 50% of total statewide water demand. These estimates vary greatly with local conditions and hydrology. In the Central Coast, groundwater provides more than 80% of the total average water use, while the San Francisco Bay area supplies only about 5% of total average year water use with groundwater (DWR, 2014).

Figure 2 shows the history of groundwater pumping in the Central Valley. Similar trends have occurred in other developed areas of California (DWR, 2003). Aggressive groundwater development earlier in the 20^{th} Century led to significant overdraft, especially in the San Joaquin Valley and in the Central and South Coast areas. The widespread lowering of groundwater levels substantially dewatered many wetlands and streams (Howard and Merrifield 2010). Groundwater overdraft in the San Joaquin and Tulare basins also caused significant land subsidence from 1945 to 1970. While the rate of land subsidence slowed in 1970s, after the State Water Project imported water to the west side of San Joaquin Valley, increased groundwater pumping, especially in the lower aquifer systems during the recent dry years (after 2005) has increased current land subsidence to over one foot per year in some areas (Sneed et al. 2013). With the current drought of 2014, reduced surface water deliveries and increasing reliance on groundwater for agricultural and municipal water uses in the Central Valley, could cause additional subsidence.

Throughout California, groundwater pumping has significantly reduced flows in rivers and streams. For example, many Sacramento Valley rivers that previously gained considerable summer flows from groundwater in the early 20^{th} century now lose flows to groundwater, primarily from lower groundwater levels due to increased groundwater pumping (TNC, 2014).

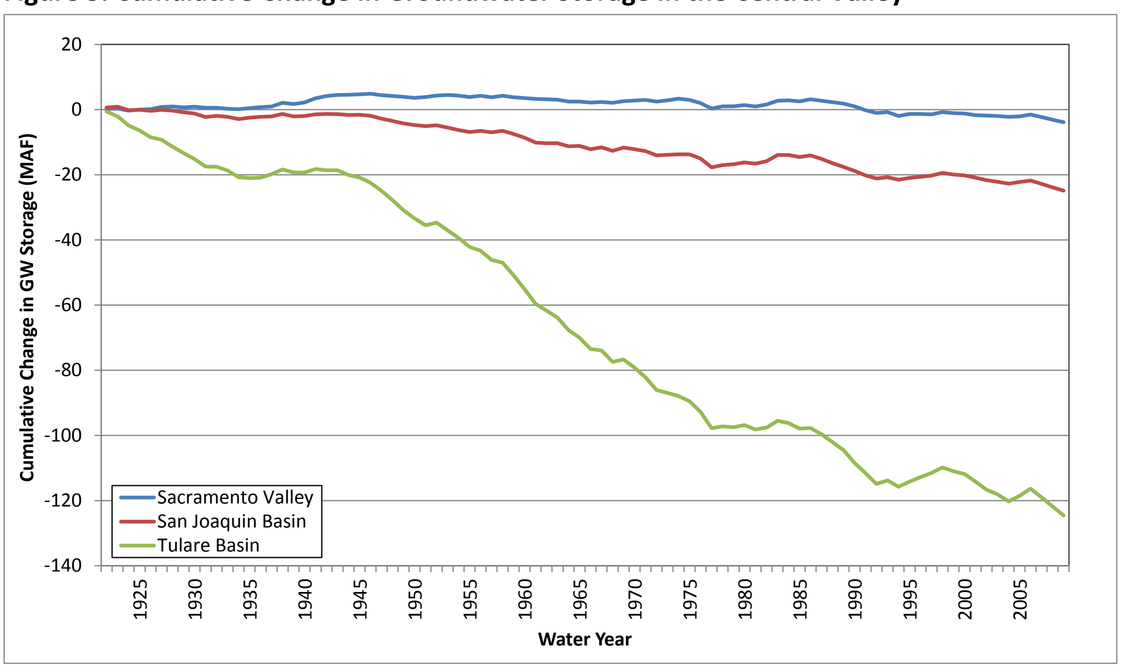
Total overdraft in Central Valley over the 20th Century is estimated to be 155 million acre feet (maf), averaging 1.9 maf per year of overdraft (TNC, 2014). Figure 3 shows the cumulative reduction in groundwater storage in the Central Valley.

Figure 2. Historical Central Valley Groundwater Pumping



Source: C2VSIM simulations 2013 (TNC, 2014)

Figure 3. Cumulative Change in Groundwater Storage in the Central Valley



Source: C2VSIM simulations (TNC, 2014)

Since 2005, limited surface water availability and the high profitability of expanded agricultural acreage have increased groundwater pumping. From 2005 to 2009, this increased groundwater use has increased depletion of groundwater storage by approximately 5.4 to 13.2 maf from Central Valley aquifers (DWR 2013); approximately 1.0 to 2.5 maf per year of groundwater depletion. In dry 2014 alone, an additional 5 maf of groundwater pumping is expected (Howitt et al. 2014). This additional groundwater storage depletion has significantly affected surface water courses and groundwater dependent ecosystems in various parts of the Central Valley, and has contributed to reduced inflows to the Delta.

California has approximately 850 maf to 1.3 billion acre-feet (DWR 1975, DWR 1994) of groundwater in storage. However, not all of this groundwater is economically or practically available, since much of it is of poor quality or is too deep for economical extraction. Of this total groundwater volume, approximately 149 to 450 maf is estimated to be useable, meaning that it occurs at depths that can be withdrawn economically and is of suitable water quality for drinking or agricultural use. However, withdrawal of this amount without compensating recharge would likely reduce surface water flows, increase land subsidence, and cause conflicts among existing water users.

Conjunctive management of surface and groundwater storage occurs in many locations and is fundamental for storing additional water in aquifers in wet years. Intentional efforts to conjunctively manage surface and groundwater storage have been very successful since the 1940s in many parts of California, including Southern California, Yolo County in northern California, and Kern County in the Tulare basin (Banks 1953; Blomquist 1992; Jenkins 1990; Vaux 1986). Many conjunctive use efforts rely on "passive" or in-lieu recharge, where farmers use surface water in wetter years which both recharges groundwater with return flows and reduces pumping from the aquifer. More active recharge also occurs, usually using water spreading (recharge) basins or managing water releases in losing reaches of streams. Regional pricing of surface and groundwater use has helped fund the availability, use, and recharge of more variable surface water supplies, as well as reduce groundwater use.

The Orange County Water District's conjunctive use activities since the 1930s have resulted in significant recovery of groundwater levels, and a well-managed aquifer storage system for that region. Santa Clara Valley Water District has implemented conjunctive use since the 1960s, recovering some of their groundwater levels and halting further land subsidence. Yuba County is another good example of successful regional conjunctive use operations, with significant recovery of groundwater levels in a previously overdrafted aquifer (Onsoy 2005).

In some areas, overdrafted aquifers have provided opportunities for regional and local groundwater banking using surplus local or imported surface water , such as in the Tulare Basin (Kern Water Bank, Semitropic Water Storage District), and parts of southern California (Eastern Riverside and San Bernardino counties). Limitations on these banking programs include the availability of surface water and infrastructure for direct or indirect recharge, some water right uncertainties for groundwater banking, access to the banked water during times of Delta shortage, and nearby impacts of water level fluctuations from banking activities.

Snowpack and Soil Moisture

Sierra-Nevada snowpack usually shifts a significant amount of winter precipitation to supply spring and summer runoff. Although snowpack storage provides a significant amount of seasonal water storage, the amount and/or timing and scale of runoff from snowpack cannot be controlled. As the climate warms, seasonal snowpack storage will be reduced, leading to some reoperation of downstream reservoirs (Tanaka, et al. 2006; Medellin et al 2008; DWR 2009).

Another form of seasonal water storage is soil moisture. This is the only form of water storage available to agriculture in non-irrigated areas, where precipitation is stored in the soil for use by natural vegetation or crops, usually over several weeks. In most of California, with its long dry season, soil moisture from winter precipitation has operational significance early in the growing season. However, without resupply from irrigation, soil storage alone is usually insufficient in quantity and reliability to support prosperous agriculture.

Water Storage Challenges

The many local, regional, and statewide purposes of water management in California make oversight, operation, and finance of the system and its many components a complex and ever-changing brew. This characterization applies to both surface and groundwater storage, whose roles within this system have changed, and will continue to change over time.

Water management objectives and conditions continue to evolve, and this evolution will demand changes in expectations for policy, planning, and operations, which are beyond the scope of this study. Major foreseeable changes include changes in climate (particularly warming and sea level rise), population growth, increased urban and agricultural water use efficiency, tightening drinking water standards, additional invasive species, landscape changes in watersheds and parts of the Sacramento-San Joaquin Delta, and changes (tightening, loosening, or both) of environmental regulations (Hanak et al. 2011). These changes will affect all aspects of California's water system, including surface water and groundwater storage.

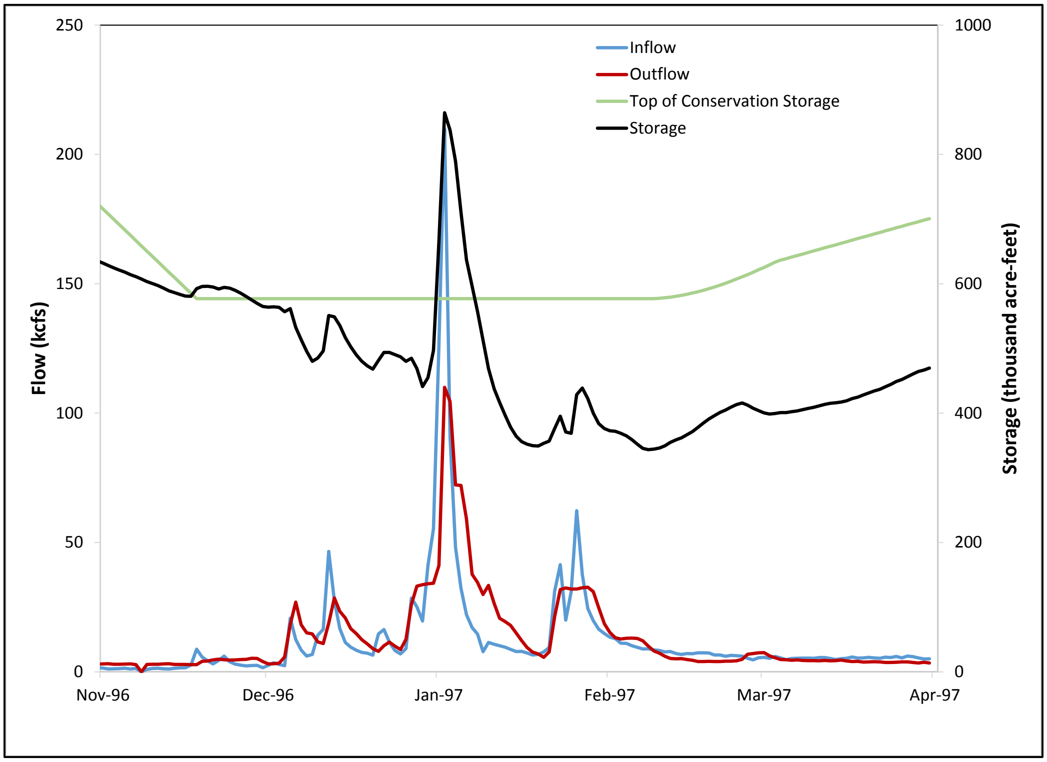
Some particularly important challenges for water storage and storage management include:

- reduced seasonal snowpack water storage with a warmer climate, encouraging some reoperation of dams, aquifers, and water conveyance and recharge; this may include revisiting the reservoir rule curves for some of the reservoirs to increase seasonal water supply pools,
- reduced water availability to fill storage due to changes in climate, increasing overall water use (including environmental uses), and reduced ability to move water across the Delta,
- efforts to restore habitats by removing some dams,
- access to water banked underground, and
- transparency in water rights and water accounting.

How Water Storage Works in California

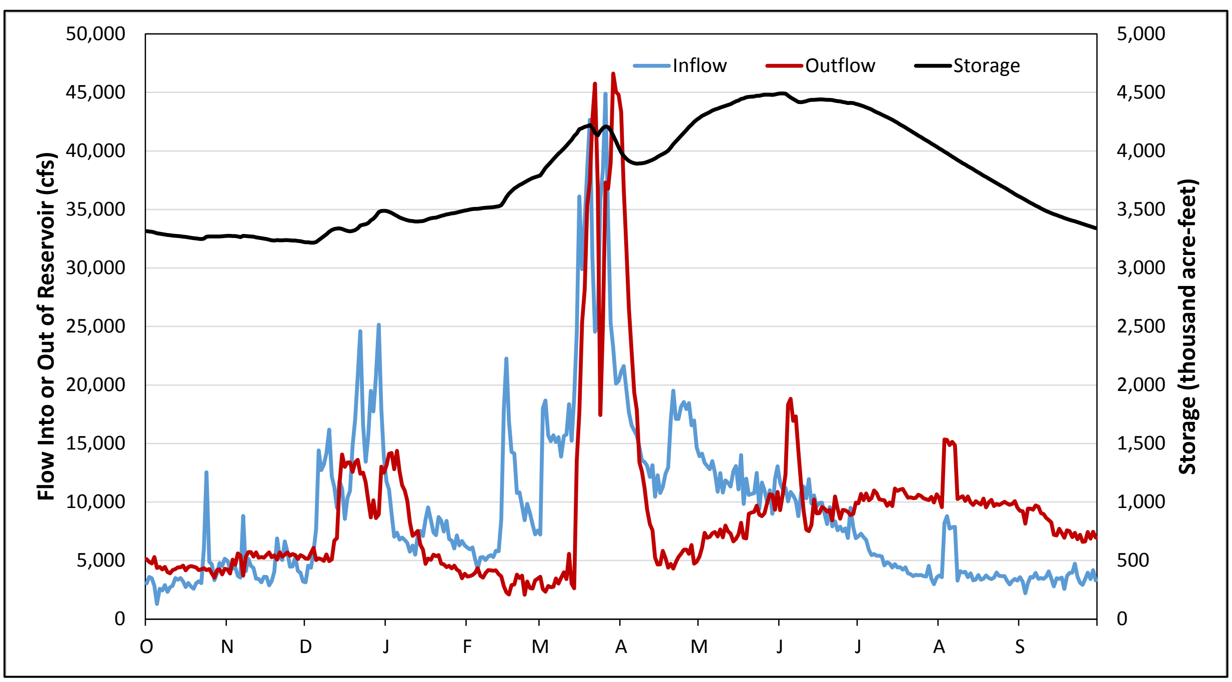
California's climate, economy, and geography drive the need to store water from times of greater abundance to serve demands in times of greater scarcity (Lund 2012; Lund and Harter 2013). Water is generally stored at times when the value of water is relatively low for use in times when the value (and scarcity) of water is relatively high. Figure 4 shows how water storage and release can respond to flood conditions over several days (Figure 4a), wet and dry seasons within a year (Figure 4b), and droughts lasting many years (Figure 4c). Consequently, the value of storage capacity and the value of stored water varies greatly with time, location, and the purposes of storage.

Figure 4a. Folsom Reservoir Storage and Flows during 1997 Flood Event



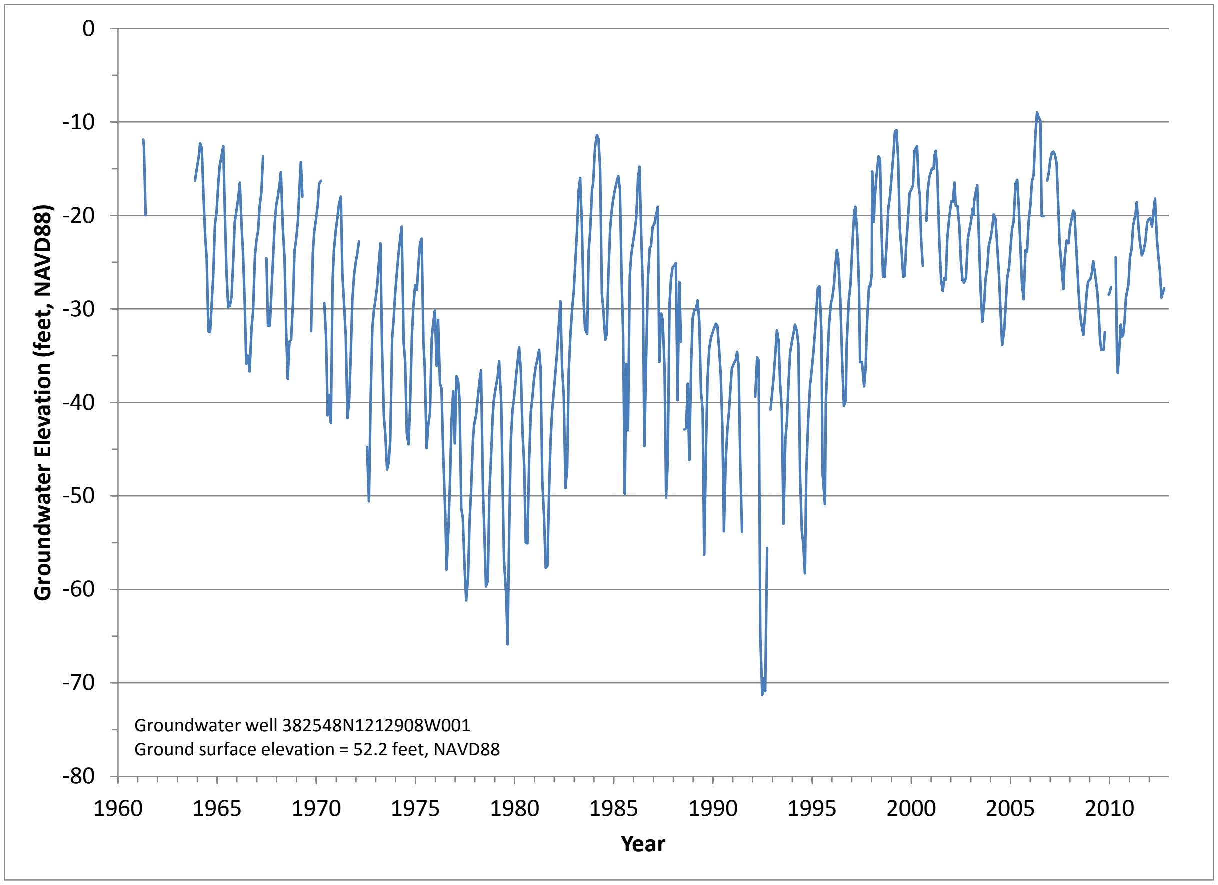
Source: USACE data (2013)

Figure 4b. Typical Seasonal Reservoir Operations



Source: CDEC data for Shasta Reservoir (2013)

Figure 4c. Typical Annual and Decadal Scale Groundwater Storage Levels (Galt, California)



Source: California Water Data Library Well No: 382548N1212908W001

Just as the value of stored water varies with time, all locations and types of water storage are not equal. Natural storage in snowpack and groundwater and managed surface and aquifer storage have important roles, but only the small portion of California's total storage in surface reservoirs and groundwater within the reach of wells can be "managed." Figure 5 summarizes total capacities of surface and groundwater storage and its use in California.

Groundwater storage capacity in California dwarfs that of surface storage, which is much more actively used. Seasonal storage tends to be more from surface reservoirs and long-term and dry year storage is more from groundwater. Some surface storage reservoirs are operated predominantly for flood control or hydropower reservoirs, although this single-purpose storage sometimes contributes to seasonal water supply storage. The currently proposed new surface storage reservoirs, discussed later in this paper, would add less than ten percent to existing surface storage capacity. Figure 6 shows how not all storage in a reservoir or aquifer is accessible and how different ranges of storage often serve different purposes, sometimes with different seasons.

Figure 5. Surface and Groundwater Storage Capacity in California and Its Seasonal and Drought Use

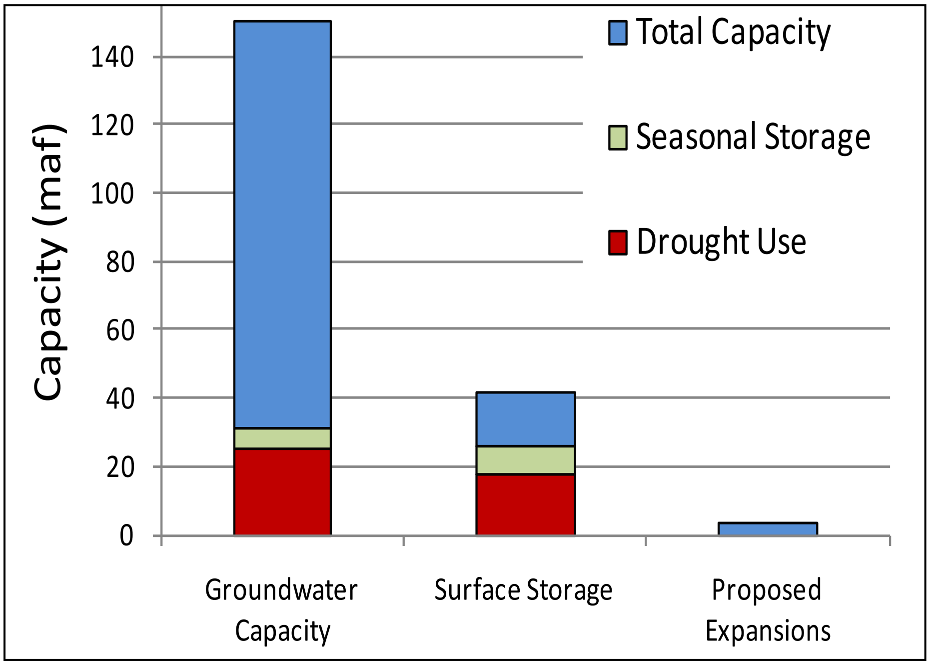
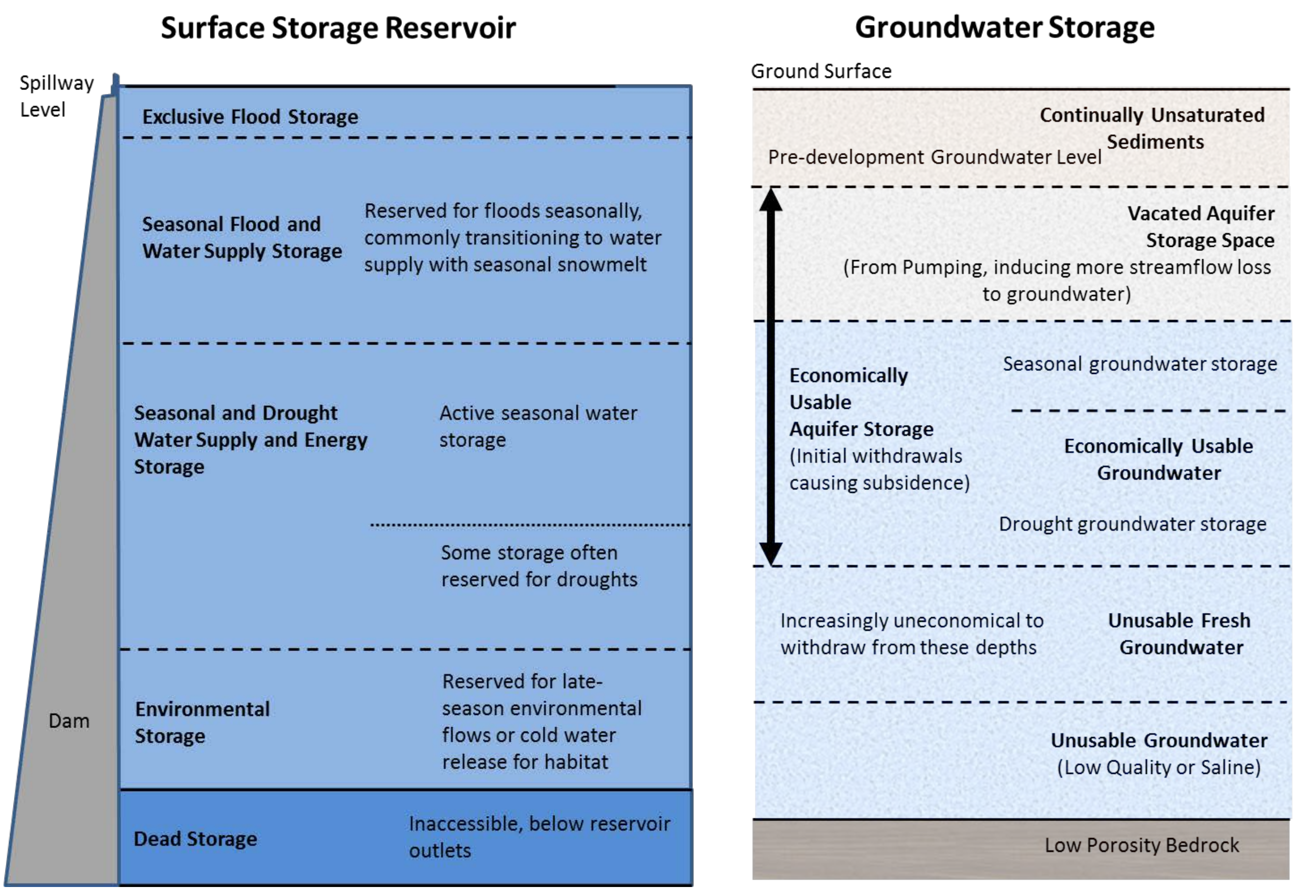


Figure 6. Common Operating Ranges for Surface and Groundwater Reservoirs



Groundwater in storage is primarily from recharge that has occurred over hundreds of thousands of years from surface water bodies (rivers, streams, and lakes), runoff from mountains, and rainfall over the ground surface. In addition, human activities during the past century, such as irrigation, contribute significantly to groundwater recharge through deep percolation of applied water.

Useable groundwater in storage is that portion of groundwater that has reasonable quality for urban or agricultural use and is within an economical depth to pump. Most wells in the Central Valley are 200 to 500 feet deep, although some wells are over 1,000 feet to tap deeper aquifer layers. Other wells are deeper still, such as in some coastal aquifers, where water wells are over 2,000 feet deep to extract deeper groundwater that is somewhat isolated from saline ocean water.

Long-term extraction of groundwater beyond its replenishment rate causes overdraft of the basin. While overdraft can have significant negative impacts, as described above, short-term depletion can provide additional storage space in the basin, providing an opportunity for deliberate underground storage of surface water. Some of California's major groundwater basins currently being overdrafted are shown in Table 2.

The storage space created as a result of historical overdraft contributes to the available groundwater storage capacity. About 250 maf of storage capacity is available statewide, of which the Central Valley comprises approximately 170 maf (DWR, 2003).

Table 2. California's Major Overdrafted Groundwater Basins

Groundwater Basin	Estimated Recent Overdraft rate (taf/yr)	Average Current Pumping (taf/yr)	Percent Pumping from Overdraft
Sacramento Valley	180	1,900	9%
San Joaquin River Basin	480	2,500	19%
Tulare Basin	1,500	5,400	28%
Salinas River Basin	26	496	5%
Pajaro River Basin	12	48	25%

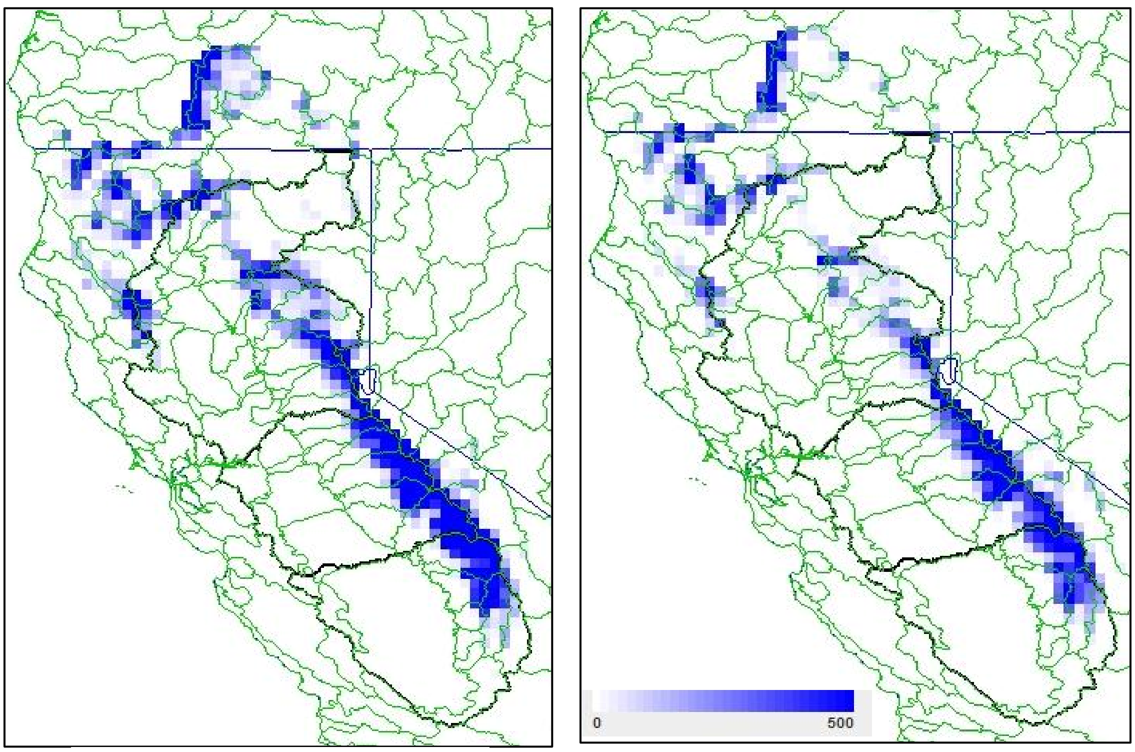
Source: (TNC 2014; MCWRA 2012; PVWMA 2013)

Working as a System

Groundwater and surface reservoirs have important and different storage capabilities. Seasonal storage (within a year) is routinely provided by surface reservoirs, whereas groundwater basins, with their greater storage capacity and generally slower recovery rates, are more important for long-term storage. The seasonal operation of surface reservoirs often supports groundwater recharge downstream, essentially transferring short-term storage into longer-term storage. Both seasonal and drought storage are augmented by natural seasonal snowmelt, soil moisture, and groundwater storage. Short-term storage for flood management and power generation is predominantly by surface water reservoirs. Groundwater alone typically can absorb little floodwater because flood flows are typically contained within the river channels or occur for a duration too short to permit significant percolation to groundwater. However, groundwater can be managed conjunctively with surface storage to increase both flood retention and water deliveries. In this case, the surface reservoir can be used during wet periods and wet years, while reducing groundwater pumping during these periods, which in turn results in increasing groundwater in storage. During dry conditions and dry years, on the other hand, when surface water may be insufficient, water previously stored in aquifers during wet periods can be extracted for beneficial use.

Seasonal snowpack in the Sierra Nevada, Cascade, and other high mountain ranges provides the most significant seasonal surface water storage. California’s water supply, flood management, ecosystems, and general water management infrastructure take advantage of snowpack shifting winter precipitation to spring and summer snowmelt. A warming climate will shift more precipitation to rain from snow and cause earlier snowmelt, significantly reducing seasonal snowpack storage and eroding the effectiveness of the current storage system and operation. Figure 7 depicts the potential loss of April 1 snow water equivalent due to climate warming by mid-century.

Figure 7. Simulated Historical and Future April 1 Snow Water Equivalent



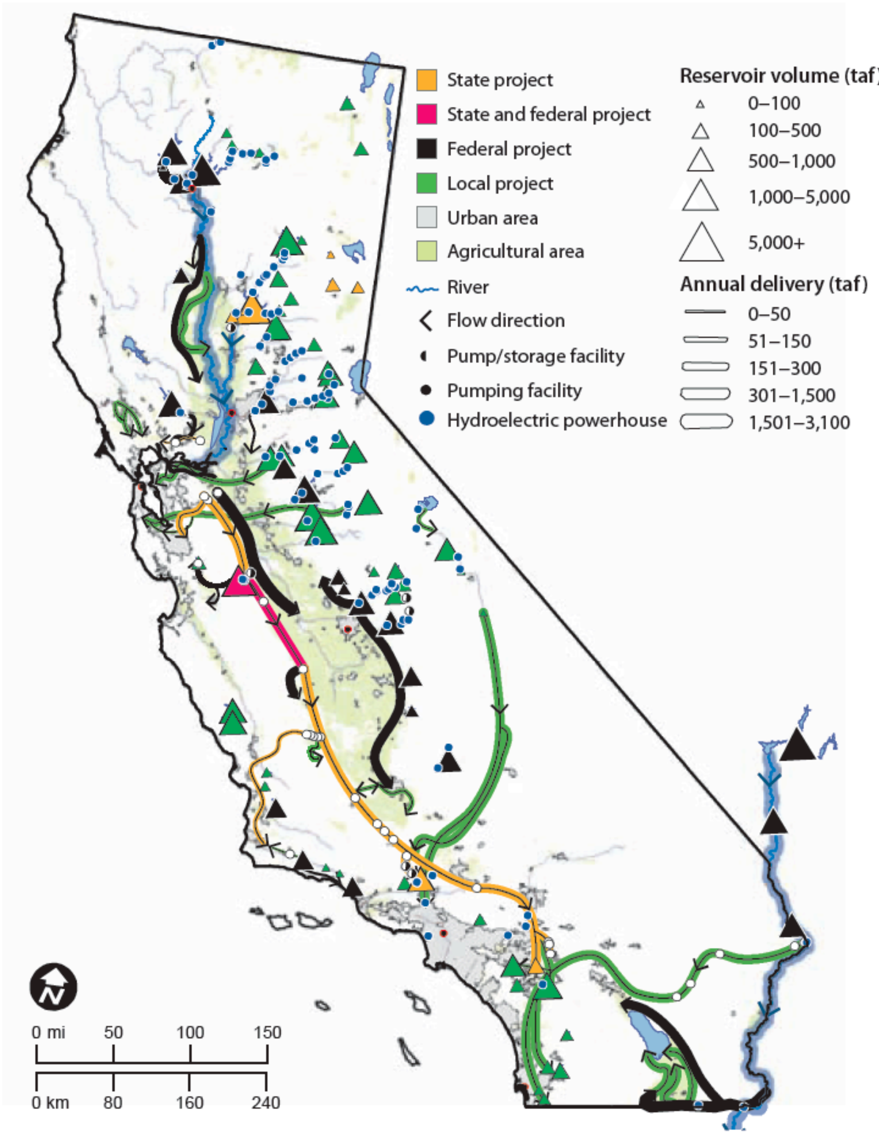
1981-2010: ~ 23.0 maf **2041-2069: ~11.7 maf**

Source: Historical and future VIC hydrological model simulations (CH2M HILL)

Water storage infrastructure and operations function as parts of a large, interacting and dynamic system that serves many purposes (Figure 8). Some implications of these interactions are summarized below.

Storage capacity often serves multiple purposes. Fortunately, storage of winter floods for spring and summer water supply is compatible with California’s climate. Storage of seasonal flood and high flows reduces downstream flooding and holds water from the wet season for agricultural and urban uses during California’s long dry season. By distributing stored floodwaters over time, the flood storage system also can increase recharge to groundwater, which can be used during dry months and years. In parts of the world where the flood season is also the main water use season, storage capacity for floods has much less ability to serve doubly for water supply.

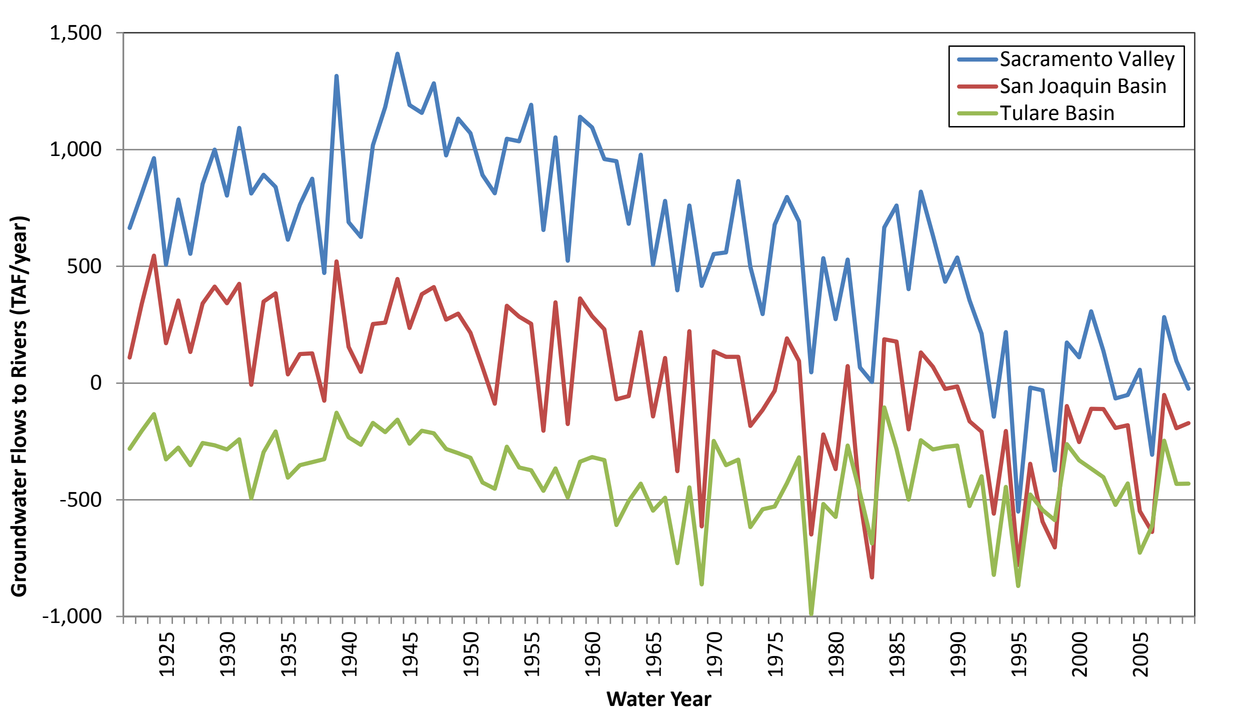
Figure 8. California's Vast Intertied Water System



Source: Hanak et al. 2011

Groundwater and surface water connect and interact in important ways. Surface water and groundwater systems in California are interconnected and substantially operate as an integrated system. During the pre-development era, groundwater levels were high enough to provide a fairly constant base inflow (baseflow) to streams. Groundwater pumping has lowered groundwater levels in many areas, reducing water flow from groundwater to streams and has often reversed these flows to the point that today, in many parts of the state, more water flows from streams to aquifers than from aquifers to streams (TNC 2014; Fleckenstein et al. 2004; Faunt et al. 2009). Figure 9 shows the surface water/groundwater interaction for Central Valley rivers and streams from the 1920s through 2008. As shown in the figure, groundwater withdrawals have reduced streamflow in Central Valley rivers by over 1 maf per year.

Figure 9. Historical Simulations Show Growing Losses from Streams to Groundwater



Source: TNC 2014

Location, location, location. The location of storage, relative to flows from source watersheds, water demands, and conveyance facilities is very important. For storage to be useful, it must be located where it can be replenished and withdrawn in quantities and at costs suitable for its intended demands. Much of California's remaining surface water and groundwater is unavailable for storage because of costs and limits of accessing it for recharge, withdrawal, or conveyance due to its location.

Groundwater is typically drawn from aquifers near the place of use. Overdraft and groundwater depressions are common in areas of concentrated pumping. For managed groundwater storage projects to be successful, the projects need to be located strategically not only in areas with large available storage space, but also where there is access to water for managed recharge, such as from recycled water, storm water, flood flows, and/or imported water. Careful analysis of feasibility of recharge relative to the source water, available storage, as well as recharge rates is required for managed recharge programs.

California has large amounts of empty groundwater storage capacity south of the Delta due to decades of overdraft. This storage capacity is hard to employ fully because of its remoteness from major available water sources. The same principle applies for surface water storage, which cannot provide water without a water supply to fill it first.

Storage capacity does not equate to water supply. Storage space must be at least partially filled before it can provide additional water supply, and numerous operational, physical, institutional, and legal constraints often limit the effective use of available storage space. These constraints include engineering restrictions on the rates at which reservoirs can be filled and emptied for safety and capacity reasons, lack of conveyance capacity to bring stored water to or from reservoirs or aquifers, water rights and contract constraints, and regulatory limitations. For water recharge to groundwater, there is often some loss of water that cannot be recaptured later by extraction wells, so the amount of water recharged exceeds its future deliveries.

Water deliveries do not increase in direct proportion to increases in additional storage capacity. Doubling of reservoir size does not double water deliveries (Hazen 1914). Water deliveries are ultimately limited by the amount of water flowing into a reservoir. A small reservoir in a watershed with variable inflows will greatly improve regular water deliveries. But, as the reservoir size increases, compared with the amount of inflow available to fill the reservoir, the available storage space is filled less and less frequently, which means that the each additional increment of added storage capacity provides less and less water supply benefit. Millerton Reservoir (with 500 taf capacity) on the San Joaquin River (with 1.7 maf/yr average flow) delivers about 800 taf/year; however, adding a 1.2 maf reservoir upstream on this river is estimated to increase deliveries by less than 80 taf (Reclamation 2014a).

Storage Limitations. The performance of California's water system is often limited by the storage and conveyance capacities available at specific times and locations, forcing available water to be under-utilized for some purposes. However these capacity limitations are often not physical, but come from environmental regulations, flood operating policies, and water rights or contracts. Storage restrictions from water rights and contracts sometimes can be loosened with water market transfers. Flood operating policy changes often require prolonged reassessments of trade-offs between flood and other objectives for a particular reservoir site. Environmental protections that affect storage operation can take many forms, including needs to store cold water to support salmon downstream, storage to support minimum or pulse flows for downstream habitat, and avoidance of release patterns that could disrupt downstream habitats.

Climate Change. Climate warming will significantly affect the effectiveness of storage in California's current water system (Buck et al. 2011; Willis et al. 2011; DWR 2009). Five effects of climate warming will be:

1) reduced winter snowpack, shifting annual streamflow from spring to winter months, something that is already happening (Aguado, et al. 1992),
2) higher evaporation and evapotranspiration rates, reducing annual streamflow by several percent and reducing groundwater recharge (Ficklin et al 2013),
3) higher crop growth and evapotranspiration rates and longer growing seasons, with variable effects on agricultural and outdoor landscaping water demands, ranging from no change to modest increases in transpiration by the same or similar crops to large increases from additional double-cropping,
4) higher stream temperatures that reduce the quantity of cold water, particularly in spring, and increase the demand for or reduce the effectiveness of reservoir releases of cold water to maintain cold water habitat downstream of reservoirs, and
5) higher sea levels that increase risk of salinization of coastal aquifers and reduce the ability of the Sacramento-San Joaquin Delta to convey stored water.

In addition, increases in the overall intensity and duration of floods and droughts also can be affected and are important areas of active research and investigation that are beyond the scope of this study.

California's existing surface storage capacity can accommodate some, but not all, seasonal shifts in streamflow from a warmer climate for hydropower, water supply, and flood management (Buck, et al. 2011; Madani and Lund 2010, Willis et al. 2011), although this accommodation comes with some inconvenience and economic losses. With proactive adaptation, groundwater also can be employed to balance shifts in seasonal streamflows by shifting more drought storage from onstream reservoirs to aquifers (Tanaka et al. 2006). Nonetheless, recent studies indicate up to 10% reductions in water deliveries and increased risk to the management of cold water releases from reservoirs for downstream fisheries (cold water pool management) due to climate change through mid-century (Bay Delta Conservation Plan 2013).

The effects of warming on fish are more severe, especially if warmer conditions are also drier. Drier conditions reduce water availability for fish flows, and warmer conditions make it harder to support fish in downstream habitats with cold water stored in reservoirs (Moyle et al. 2013).

Severe and prolonged droughts in California can last for many decades (Kleppea et al 2011). Such droughts would be seen as a drier climate for several generations. These drier conditions would diminish the deliveries and effectiveness of much of California's water storage infrastructure (Harou et al. 2010).

Storage Study Efforts to Date

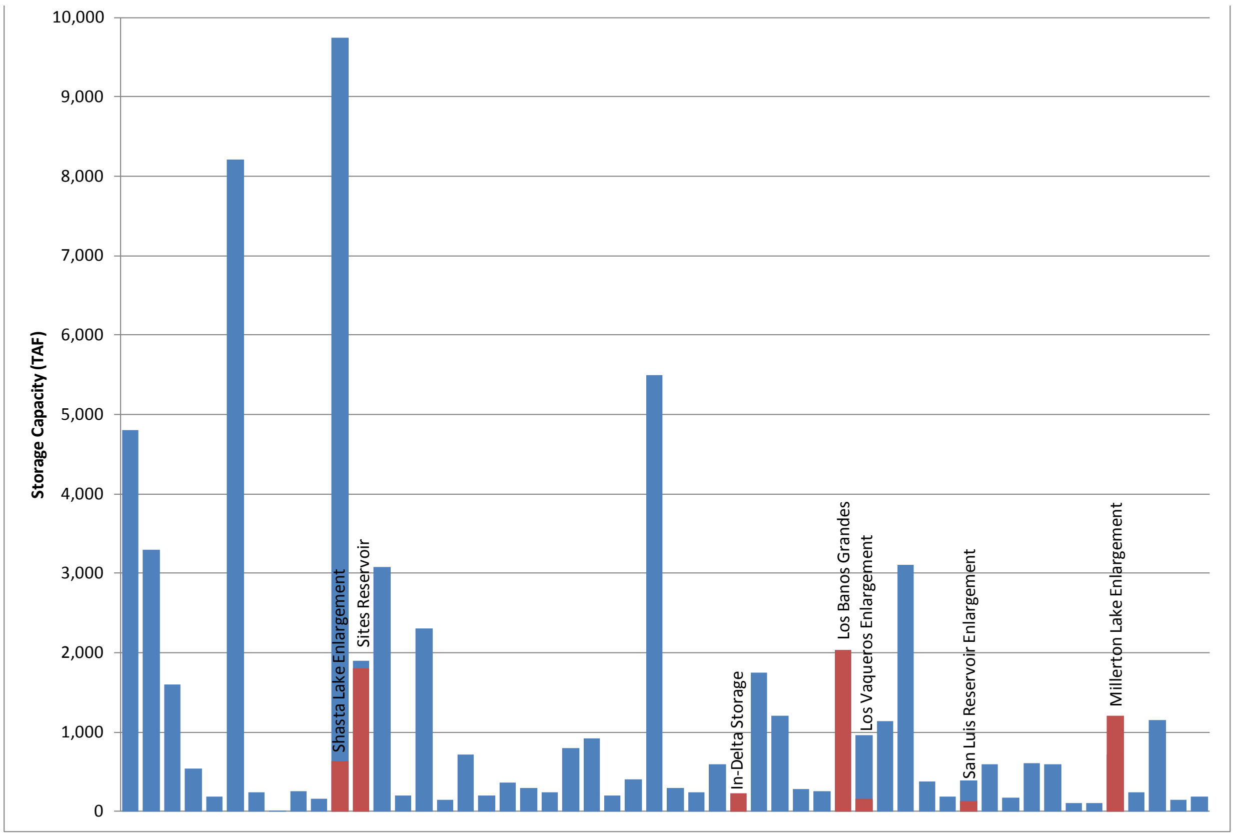
For nearly a hundred years local, state, and federal governments and research institutions throughout the state have studied surface water storage and new or expanded storage facilities in California.

The CALFED program in the early 2000s, drawing on many previous studies, performed a comprehensive screening of additional surface storage options for the Central Valley. The initial screening considered over 50 surface storage locations with a cumulative additional storage capacity of over 60 maf (Figure 10). From these initial storage sites, five potential large projects (Shasta Lake enlargement, Sites Reservoir, Los Vaqueros Reservoir enlargement, In-Delta storage, and Millerton Lake enlargement) with a potential for 4.2 maf of new surface storage were selected for further study. Subsequent investigations of these options are continuing to seek improvements in water supply reliability, water quality, environmental flows, and other benefits.

In addition, regional and local storage continues to be investigated to support local water supply and flood management. For example, the Metropolitan Water District of Southern California completed Diamond Valley Reservoir in 1999, adding 800 thousand acre feet (taf) of storage for southern California. Contra Costa Water District increased Los Vaqueros Reservoir to 160 taf in 2012. Similarly, the San Diego County Water Authority is increasing San Vicente Reservoir to add 152 taf for local supply resiliency to earthquakes. In total, more than 27 maf of new surface and groundwater storage projects are being considered statewide, often by local agencies.

Many state, regional, and local efforts are encouraging more proactive management of groundwater capacity to store surface water during wet years and seasons, known as conjunctive use of surface water and groundwater. Another concept in use of groundwater and surface water resources in a conjunctive mode is groundwater banking opportunities. In this case, local water agencies which have access to surface water use artificial or in-lieu means to recharge the groundwater system and bank the surface water when available, with the premise of using the banked water during times that surface water is not available. Many local agencies are starting to implement such programs. Local groundwater banking provides opportunities to store water in a relatively safe and economic environment, closer to the demand areas. In addition to improving the use and storage of existing water sources, some of these efforts seek to develop some new supplies by treating urban wastewater, stormwater and brackish or poor quality groundwater. Many of these efforts are in Southern California. Up to 1 maf of groundwater storage or conjunctive use was targeted for further study in the CALFED investigations, primarily in the San Joaquin and Tulare basins.

Figure 10. Surface Storage Options Investigated in CALFED Review (Red bars are storage programs now being actively studied by local, state and/or federal agencies)



Source: Data from CALFED (2000)

Much of the potential new storage capacity is in the Central Valley and along the major state and federal water project conveyance systems. The Sacramento and San Joaquin Rivers and Central Valley Project and State Water Project canals are particularly important for making stored water useful over large parts of California.

Table 3 summarizes major on-going surface and groundwater storage studies in California. The CALFED storage programs are currently being evaluated under the Integrated Storage Investigations by DWR and Reclamation. DWR also has several other active storage-related studies underway: the System Reoperation Study, the FloodSafe program, and the California Water Plan. The USACE and local agencies also participate in the FloodSafe program.

A statewide inventory of groundwater management plans shows that many regional and local agencies are leading efforts to evaluate and expand groundwater storage and banking, including Semitropic Water Storage District, Sacramento and San Joaquin counties, Orange County Water District, and Eastern Municipal Water District. In recent years, local banking projects have drawn attention from state, regional, and local groundwater policy makers. Some potential advantages of local groundwater banking programs are that they are constructed and maintained for local agricultural and municipal uses, more supported by local governments, and require lower water transmission and distribution costs due to the proximity of demands.

Table 3. Summary of Major On-Going Storage Investigations

Proposal	Region	Owner/ Proponent and Description	Capacity, taf
Surface Storage Programs			
Shasta Lake Enlargement	Sacramento	Reclamation/DWR - On-Stream Storage to increase regulating capabilities and yield opportunities	Up to 640
Sites Reservoir	Sacramento Valley	DWR/Reclamation/Sites JPA - Off-Stream Storage for local and system-wide yield opportunities	1,200 to 1,900
In-Delta Storage	Sac. -San Joaquin Delta	Island Storage in Central or Southern Delta for Delta flows or exports	230
Los Vaqueros Enlargement	Delta	Reclamation/CCWD - Water supply storage off California Aqueduct or Delta-Mendota Canal	Up to 965
Millerton Lake Enlargement	San Joaquin River	Reclamation/DWR - On-Stream Storage to increase flow regulating opportunities	720
San Luis Enlargement	San Joaquin Valley	Reclamation/DWR - Increased off-stream storage for improved CVP and SWP deliveries	370
Groundwater Storage Programs			
Sacramento Valley Region	Sacramento Valley	Local entities - Local and regional groundwater banking for water supply and the environment.	Up to 3,500
San Joaquin Basin	San Joaquin Basin	Local Entities - Madera Ranch and similar groundwater banking opportunities for water supply storage.	Up to 2,500
Tulare Basin	Tulare Basin	Local Entities - Kern and Semitropic water banks successfully operate, and other groundwater banking are being investigated.	Up to 12,000
Other local and regional Storage opportunities	Southern California, Central and South Coast	Local and Regional Entities - Various local and regional groundwater storage programs	Up to 4,000

The Need for a Different Approach

California's water system has been built piecemeal over many years, with most projects being independently conceived and implemented incrementally. But California has come to manage water infrastructure more as an integrated system. Excess flows in wetter years from streams and reservoirs in northern California are shifted to surface water and groundwater storage in the southern Central Valley and southern California for drought storage. Flood storage to protect Sacramento is augmented by shifting water from Folsom reservoir to other reservoirs. New Bullard's Bar reservoir in Yuba County is coordinated with operation of the SWP's Oroville Reservoir to better protect Marysville and other downstream communities. Aqueducts connect water users to a wider range of water sources and storage locations and facilitate voluntary exchanges among users. Water market transfers increase the system's adaptability to changes in water availability, water demands, and climate.

Yet most studies of potential water storage projects have been "project studies", where a particular proposed project is evaluated in relative isolation from other water storage and non-storage management options regionally and statewide. Such project-level analysis continues today with studies of surface water and groundwater storage projects, such as Sites Reservoir, Temperance Flat, Los Vaqueros, and Madera Ranch water storage projects. Authorizing legislation for project studies often limits the options, locations, and benefits to be evaluated in an integrated context from the onset. Further, much of the surface water storage and delivery facilities have been planned, designed, and developed with little coordination with groundwater supplies or groundwater storage.

The true value of water storage in California is driven by its ability to be useful as a component integrated into a complex and changing system with diverse and evolving purposes for a somewhat uncertain future.

Accordingly, we propose a more integrated approach where "system studies" of water infrastructure would better reflect the integration of various types of storage and other relevant conveyance and distribution facilities. Such studies would also better highlight promising actions of all types for the broad water management purposes of California. Water system improvement studies should move from project justification studies to studies that identify the most promising projects regionally and statewide for a variety of purposes, and those that help improve the adaptability of the system for a range of likely future demands and climatic conditions.

Some potential advantages of identifying candidate water management actions using an integrated system perspective are:

- Lower costs and greater overall effectiveness from
  - better integration of supplies, demands, infrastructure operations, and investments,
  - better integrating local, regional, and statewide management and investments,
  - better use and adaptation of existing facilities, through integration of operations or re-operations to avoid or reduce needs for new capital investments, and
  - better identification and estimation of likely system-wide and local benefits and more complete consideration of alternative costs and policies;
- More adaptable systems, designed and funded to serve multiple purposes and better able to accommodate future changes;
- Broader political and financial support for actions, because a broader range of interests are explicitly considered and balanced in the analysis;
- More flexible integrated water system management that provides more resilience in extreme conditions, such as short-term or long-term droughts; and

- Water operations that are designed to support multiple habitat needs – wetlands, riparian, floodplain and instream flow needs – to optimize environmental water uses in better balance with the agricultural and municipal demands.

Major elements of a system-based approach are:

- Emphasis on managing local, regional, and statewide facilities as an integrated system with local, regional, and statewide consequences;
- Emphasis on integrating the roles and effectiveness of various storage types to supply current and future demands;
- More rigorously evaluating operational flexibility under variable hydrologic and climatologic conditions;
- Use of an integrated operational strategy to optimize the use of the finite resources in a sustainable manner;
- Consideration of multiple water, energy, and ecological purposes that depend on the water system and use of performance measures to ensure benefits from more integrated management;
- Proactive inclusion of ecosystem needs as part of planning and systemwide operations rather than as post-hoc constraints on a system designed primarily for other purposes;
- Recognition and incorporation of uncertainty in analysis and decision-making;
- Quantitative assessment of regional and local water availability, costs, decisions, and performance to provide a common technical basis for discussion and policy-making and trade-offs among alternatives;
- Broad consideration of management options including new supply development, demand management, facility development or modification, system reoperation, and policy/institutional changes and cooperation at local, regional, and statewide levels; and
- Application of simulation and optimization modeling to identify promising alternatives (optimization) and quantify their effectiveness (simulation) under a range of conditions Palmer et al. 1982; Needham et al 2000).

Elements of a system-based approach have been employed in California by regional water agencies, university researchers, and private companies. Examples of efforts that embody a system-based approach include:

- Statewide economic optimization of California's water system using the CALVIN model (Draper et al 2003; Jenkins et al. 2004; Pulido et al. 2004; Tanaka et al. 2006; Harou et al. 2010; Buck et al. 2011; Ragatz 2013; Chou 2013; Nelson 2014),
- Metropolitan Water District of Southern California's Integrated Resource Plan Analyses,
- Reclamation's Colorado River Basin Study and Sacramento-San Joaquin Rivers Basin Study,
- San Diego County Water Authority's Regional Facilities Master Plan, and
- Santa Ana Watershed Project Authority's (SAWPA) IRWM & One Water One Watershed (OWOW) Program.

Some of these analysis and planning efforts have been quite thorough and illuminate the promise of the approach we propose.

Economic Optimization Analysis of Reservoir Value: Pointing towards Integrated Analyses

Example storage valuation results from an integrated system optimization model are in Table 4 (Ragatz 2013). The CALVIN hydroeconomic model of statewide water supply coarsely integrates statewide hydrology, storage, conveyance, and treatment infrastructure, environmental flows, and economic values of agricultural, urban, and hydropower water uses (Draper et al. 2003). The model maximizes overall economic performance over a 72-year period.

Table 4 shows estimates of the economic value of expanding selected reservoirs ($/year per unit of expanded storage capacity) under various climate, Delta water export, and urban water conservation conditions. Similar results are available for infrastructure and demands statewide.[1]

Table 4. Estimated annual economic water supply values of expanding surface reservoirs under different climate, Delta export, and water conservation conditions, CALVIN, $/yr per acre-ft of expanded storage capacity (Ragatz 2013).

	Historical climate				Warmer, drier climate			
	0% urban conservation		30% urban conservation		0% urban conservation		30% urban conservation	
Reservoir	Full exports	No exports	Full exports	No exports	Full exports	No exports	Full exports	No exports
Claire Engle	3	3	3	3	39	30	32	32
Shasta	8	8	8	8	67	34	51	34
Oroville	15	11	13	10	78	18	66	17
N. Bullard's Bar	18	17	17	17	156	19	90	19
Folsom	13	10	11	9	153	20	85	15
Pardee	2	5	1	1	14	32	20	41
New Melones	9	10	9	10	3	3	3	5
Hetch Hetchy	6	7	5	7	7	6	5	7
New Don Pedro	8	9	8	8	4	3	4	5
Millerton	6	95	5	62	37	120	56	33
Pine Flat	6	95	5	62	20	103	51	95
Kaweah	56	457	47	379	269	263	225	254
Success	49	403	42	340	361	361	308	357
Isabella	4	46	1	15	32	76	32	5
Grant Lake	52	116	44	76	0	0	0	0

In these results, the value of increasing water storage north of the Delta (purple) is heavily influenced by the ability to export water to drier parts of the state with greater water demands. Greater water conservation modestly reduced the value of expanded storage, and a warmer drier climate greatly increases the value of expanding storage capacities, unless Delta exports capacity is eliminated.

South of the Delta, eliminating Delta export conveyance increases the value of increased storage capacity. Reducing urban water demands again reduced the value of increasing storage capacity. But a warmer drier climate increases the value of additional storage on some rivers, but decreases the value of water storage on streams that already have considerable storage capacity relative to inflows. In effect, for New Melones, New Don Pedro, and Grant Lake reservoirs (yellow), the drier climate makes full utilization of existing storage capacity more difficult and rare, reducing the average annual value of expanding storage.

These results illustrate many of the principles of water storage use and value in an integrated system. Storage value varies greatly with location, inflow climate, and water demand conditions.

A System-Based Pilot Simulation Analysis

To illustrate elements of our proposed systems-based approach using existing simulation models, we developed a pilot study of storage options in the Central Valley has been developed. The pilot analysis considers two simplified surface storage and two groundwater storage configurations, each facility having approximately 2 maf of storage capacity. One surface storage facility and one groundwater facility were located north of the Delta (in the Sacramento Valley), and one each south of the Delta (in the San Joaquin Valley). The hypothetical storage facilities were analyzed as integrated facilities within the intertied state and federal water system. For this pilot analysis, the size of the facilities was selected for illustration purposes and based on the authors' general sense of the size of additional storage that might be considered or proposed. The locations were selected not to mirror any specific storage proposals but to represent a range of geographic possibilities and general operational mechanisms within the intertied state system. For the analysis, the storage configurations are operated for both water supply and environmental flows. Management of the new storage is integrated with existing storage and conveyance to improve overall system efficiency. The pilot study's main assumptions are summarized in Table 5. Detailed assumptions are in Appendix A.

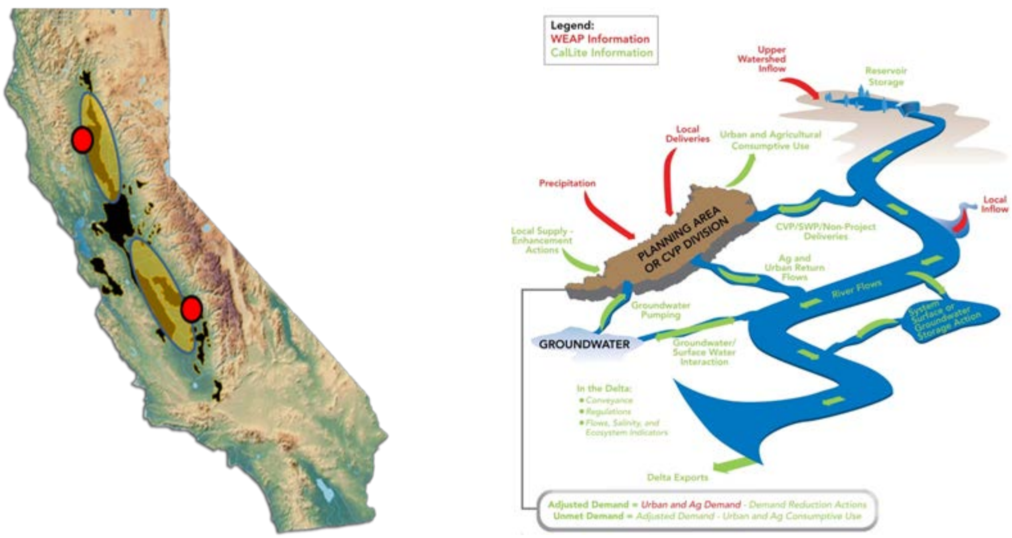
Table 5. Summary Description of the Pilot Study Storage Analysis

Characteristic	Description
Objectives	1. Improve dry-year water delivery reliability 2. Improved ability to meet Delta environmental flow and Sacramento River temperature objectives
Period of Evaluation	82 years of historical hydroclimate 1922-2003
New Surface Storage options	1. North of Delta off-stream surface storage of 2 maf with diversion from/to the Sacramento River; 2. South of Delta off-stream surface storage of 2 maf with conveyance from/to the California Aqueduct and Delta Mendota Canal
New Groundwater Storage options	1. Management of up to 2 maf of groundwater storage in the Sacramento area with conveyance integration with the American and Sacramento Rivers; 2. Management of up to 2 maf of groundwater storage in Madera County with conveyance integration with the San Joaquin River, Delta Mendota Canal, and Friant-Kern Canal
System Operational Assumptions	1. Diversions to new storage allowed only when environmental flows are already satisfied. 2. Allow pre-release from existing storage to new facilities to improve storage balancing. 3. Release storage from new facilities to increase performance against the two main objectives.
Future Climate and Socio-economic Cases	Historical hydrology, *Current Trends* socioeconomic conditions
Future Regulatory/ Delta Conveyance Assumptions	1. Existing Delta conveyance and regulations as described in BDCP No Action 2. Future Delta conveyance and regulations in the BDCP Alternative 4
Resources Evaluated	Water delivery, ecological, water quality, flood control, hydroelectric power, and recreation resources

The pilot study examined storage options with the CalLite water resources model as described in Appendix A. Historical hydrologic conditions were adopted from the Sacramento-San Joaquin Basins Study (Reclamation 2014b). Groundwater storage capacity and the ability to recharge and extract water from the aquifer was developed from California's C2VSIM groundwater-surface water system model (Brush et al. 2013) analyses and simplified for integration in the CalLite model simulations. C2VSIM is an application of the Integrated Water Flow Model (IWFM) to the Central Valley. A new version of the model with refined spatial discretization and grid network has been developed and is used for this study (Taghavi et al. 2013). Figure 11 depicts the general location of the surface and groundwater storage programs and the integrated hydrologic system included in the CalLite model.

A discussion of results from the model simulations is provided below to illustrate the types of insights that can come from more integrated system analysis.

Figure 11. General Location of the Surface and Groundwater Storage Programs and the Integrated Hydrologic System included in the CalLite Model



How Much Storage can be Effectively Used? (Use of Surface and Groundwater Storage).

The pilot analysis included simulations of each of the four storage options (two surface storage and two groundwater storage options) described above. An 82-year trace of storage in the surface facilities appears in Figure 12 for the historical climate. The additional Sacramento Valley surface storage fills during wet periods and is released during dry periods to improve water delivery reliability or to preserve coldwater pool reserves in existing reservoirs during these years. Most of water made available from the additional storage is used to provide otherwise unmet needs during drier years. This operation is typical for offstream reservoirs in California.

For the additional San Joaquin Valley (SJV) surface storage option, only about 300 to 400 taf, of the additional 2 maf of storage capacity made available in that region was effectively used. Storage up to approximately 1 maf is used once during an extended wet period. The limited use of SJV surface storage is largely due to limited availability of water from the Delta to fill the reservoir (assumed conveyance was limited to that which could be provided via California Aqueduct and Delta Mendota Canal). During wet periods, water must first meet existing demands and environmental requirements before diversions to the new storage can be considered. In addition to upstream demands, existing Delta conveyance limitations further constrain wet period diversions that might have helped fill the 2 maf of additional surface storage capacity in the San Joaquin Valley.

Figure 12. Simulated Use of Additional Sacramento Valley and San Joaquin Valley Surface Storage: ***Sacramento Valley can better use new surface storage alone than the San Joaquin Valley***, CalLite simulation results with the historical climate

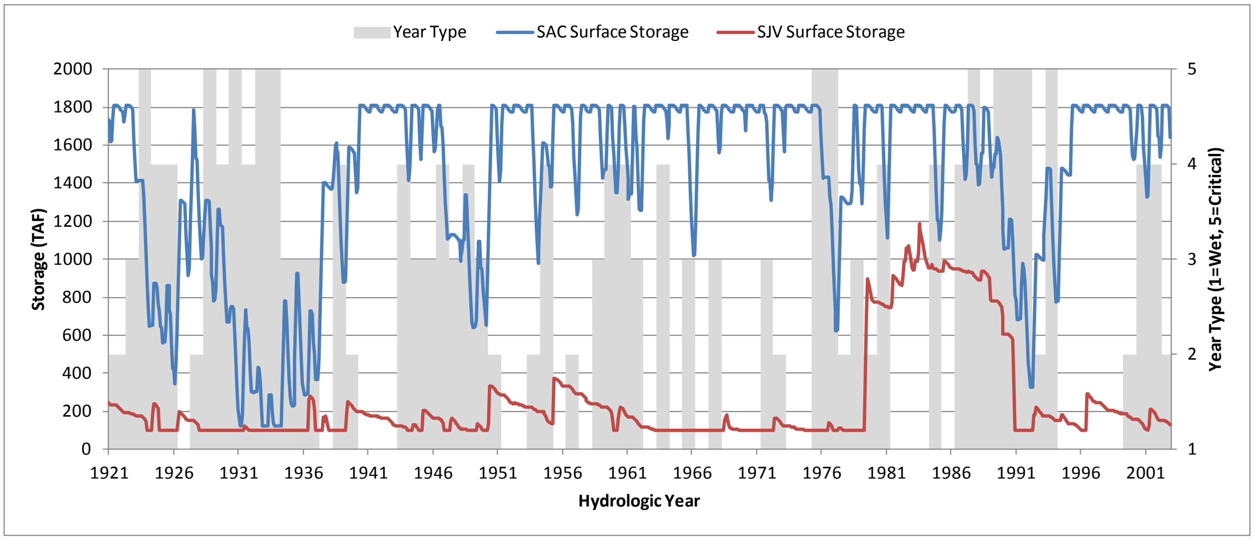
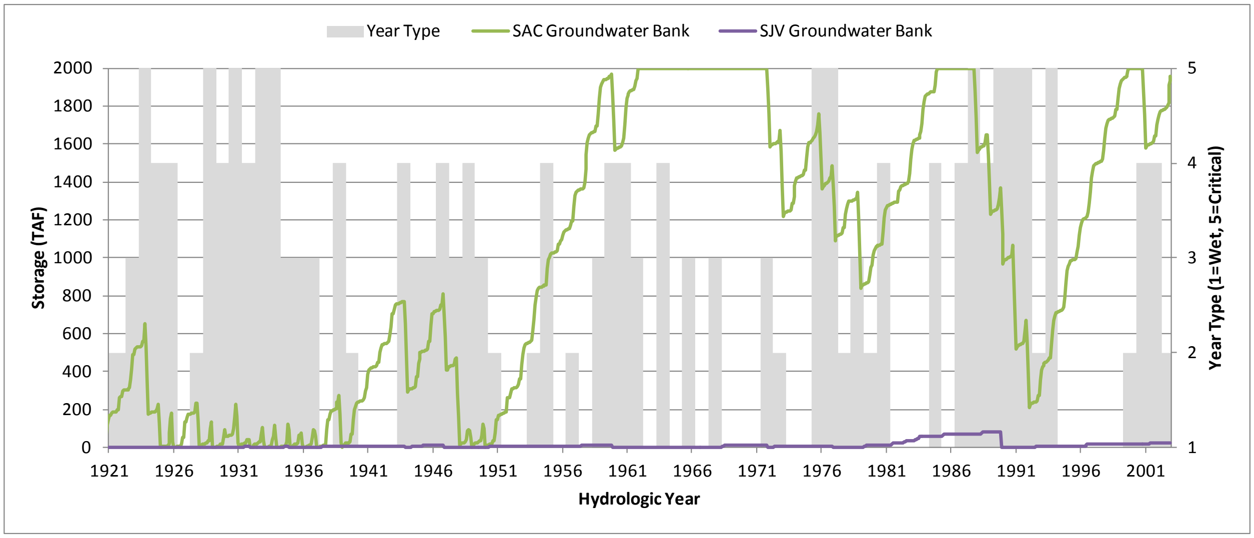


Figure 13 shows the similar 82-year period trace for the groundwater storage options considered in the Sacramento and San Joaquin Valleys for the historical climate. To get the maximum groundwater storage with minimal recharge facilities (and expense), of the three typical groundwater recharge methods (surface spreading, direct injection, or in-lieu recharge), the in-lieu recharge method was selected for this pilot study. "In-lieu" recharge programs supply existing groundwater users overlying a depleted aquifer with surface water during wetter years to increase groundwater levels due to reduced pumping in those times. Reduced groundwater pumping during the surface water delivery period allows groundwater that would have been pumped, to stay in storage and increase storage over time. During dry periods or periods with limited surface water supplies, banked groundwater becomes a source of supply. The seasonal operation of in-lieu groundwater banking depends on seasonal water demands and water availability. Since most water use for in-lieu operation is for agricultural purposes, surface water can be delivered in lieu of groundwater use only during the irrigation season. However, winter and spring is when excess surface water is most available, and when irrigation demands are the lowest. This seasonal mismatch between supply and demand limits in-lieu-based groundwater banking, especially if the operation is not integrated with larger system operations. As seen in Figure 13, about half of the available new groundwater storage capacity (about 1 maf) was used in the Sacramento Valley, until a long sequence of wet periods allowed the groundwater storage to fill. It is likely that an improved operation of the Sacramento Valley groundwater storage operated in this way would effectively use no more than 1.2 to 1.5 maf of storage capacity. In the San Joaquin Valley, however, less than 50 taf of groundwater storage capacity could be used due to inability to provide water for in-lieu demands, which do not coincide with the timing of greatest water availability from the Delta.

There are clear physical limits on useable additional surface and groundwater storage capacity in different parts of California under today's conveyance, climate, and policy and regulatory conditions. Under these conditions, larger amounts of storage capacity could not be utilized and would likely not be cost-effective.

Figure 13. Simulated Use of Sacramento Valley and San Joaquin Valley Groundwater Bank Storage: ***Sacramento Valley can better use expanded in-lieu groundwater storage alone than the San Joaquin Valley***, CalLite simulations for the historical climate



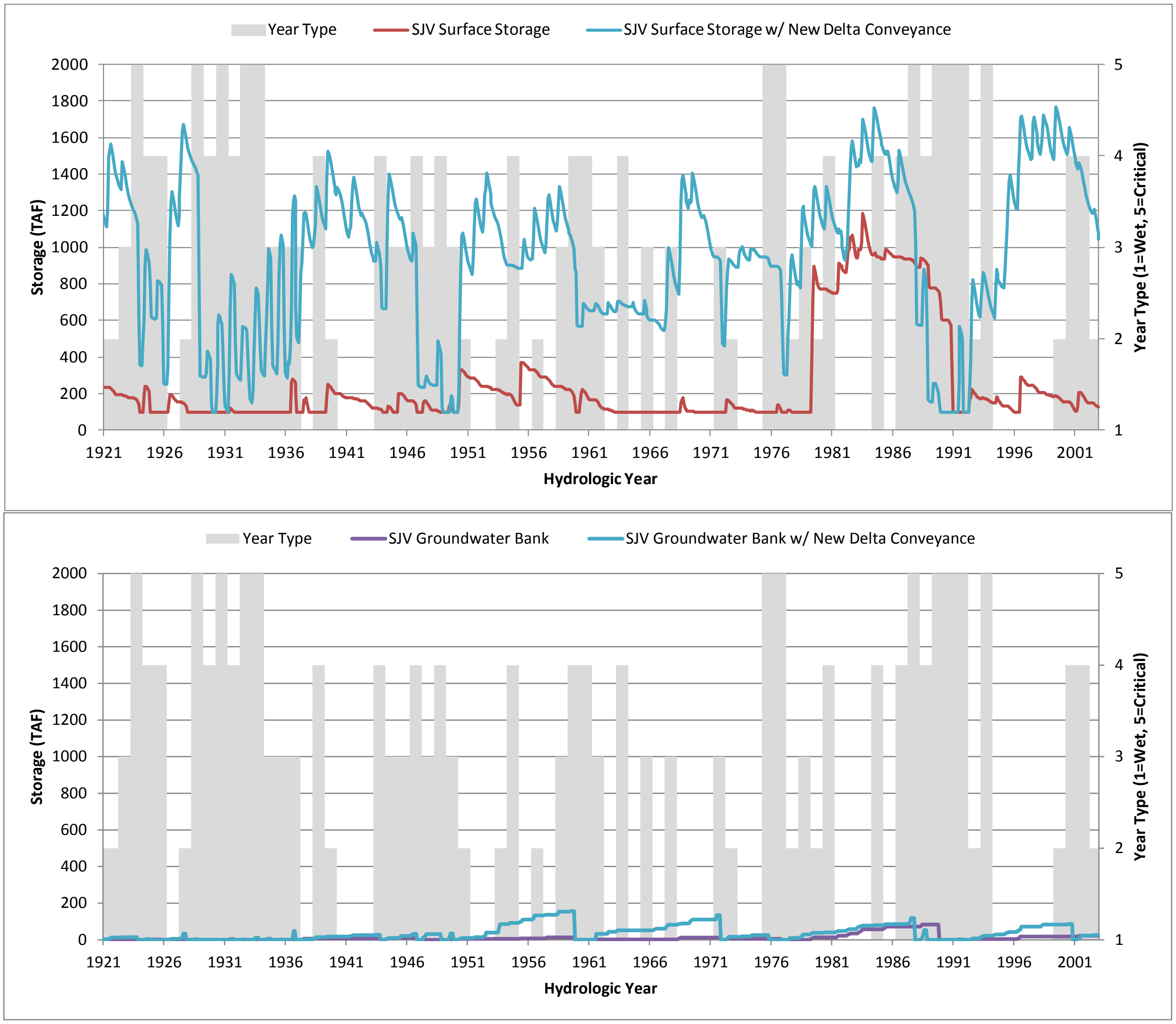
System Integration is Key (Sensitivity of Storage Operations to Delta Conveyance)

The use and benefits of storage depend strongly on other parts of the system. For this pilot we explored two major integration aspects that help us understand linkages with other infrastructure and conjunctive use options. First, we consider changes in the value of surface storage in the San Joaquin Valley with improved Delta conveyance. Second, we consider operating surface and groundwater storage in tandem to capitalize on their combined relative strengths.

Figure 14 shows the use of San Joaquin Valley surface storage under existing conveyance and with new conveyance similar to that described in the Bay Delta Conservation Plan (BDCP). While only a maximum of 1.2 maf of capacity was used with existing conveyance, nearly 1.8 maf could be used (and used much more frequently) in simulations with improved Delta conveyance. Improved conveyance allows more diversion of flows during wet periods and the new surface storage allows this water to be captured. While significantly more limited than surface storage use due in large part to the mismatch between when water was available and when it could be used for in-lieu recharge, SJV groundwater storage also was used more with improved Delta conveyance, with maximum use growing from 50 taf with existing conveyance to approximately 200 taf of new storage capacity with improved Delta conveyance.

Sacramento Valley storage utilization was relatively insensitive to Delta conveyance assumptions since current conveyance conditions in the Delta do not significantly constrain moving available water into the new Sacramento Valley storage locations.

Figure 14. Simulated Use of Additional San Joaquin Valley Surface Storage (top) and Groundwater Bank Storage (bottom) with Existing and New Delta Conveyance: *New Delta Conveyance makes San Joaquin Valley Surface Storage and Groundwater Bank Storage more useful*, CalLite with the historical climate



Integration of Surface and Groundwater Storage (Integration Magnifies Performance)

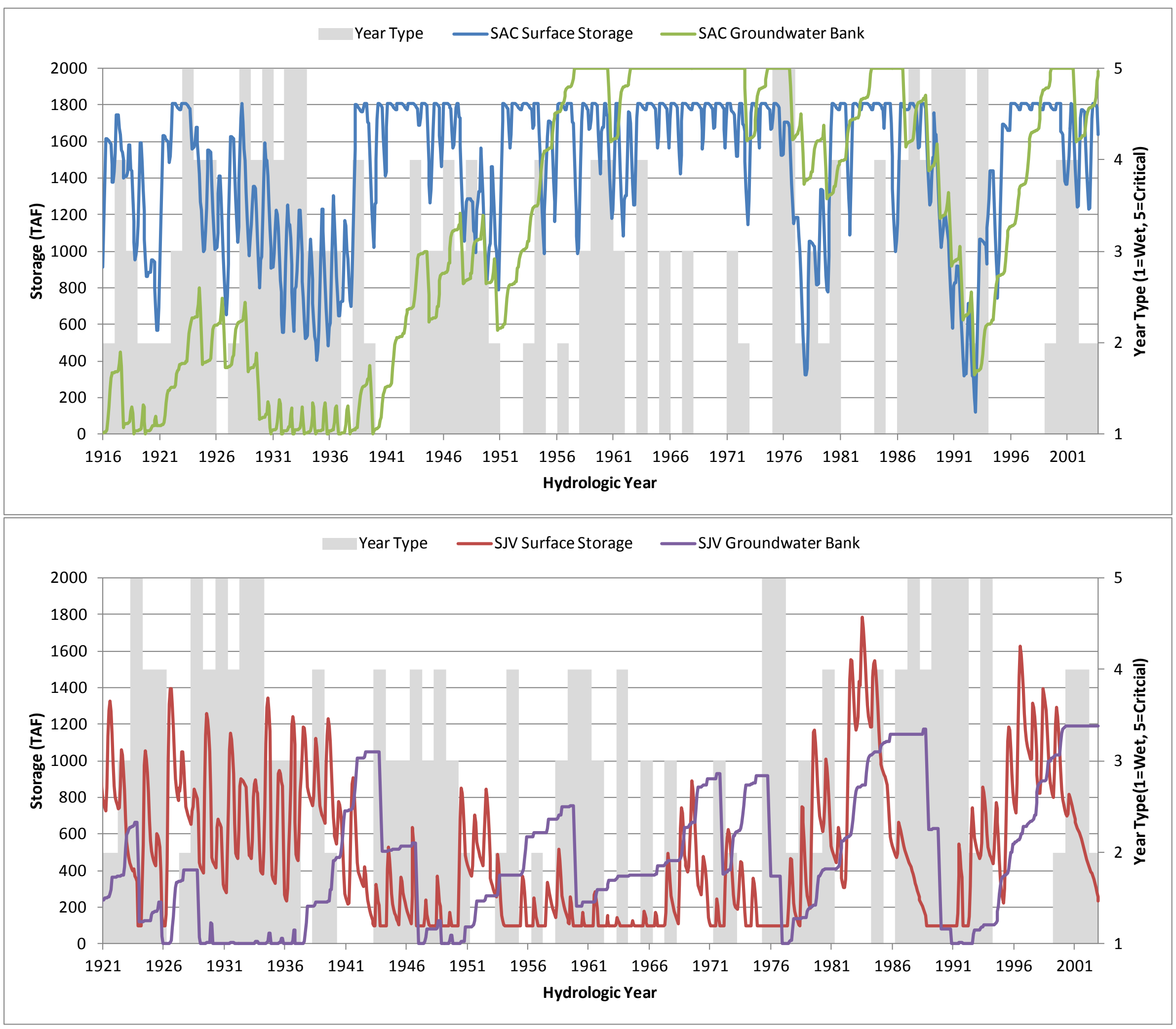
Surface and groundwater storage have historically been planned and managed as relatively independent resources.[2] However, enhanced integration of surface and groundwater storage could significantly improve water management, reduce rates of groundwater declines, adapt to climate change, and optimize new infrastructure investments (Jenkins et al 2004; Tanaka et al.

[2] A major exception is the Friant project which explicitly considered groundwater replenishment for parts of its service area.

2006). The pilot analysis included two simulations that specifically targeted integrated surface-groundwater storage operations to improve the combined use of these assets. In these simulations, surface storage was operated to store water that was available during wet periods (wet months or wet years), but then released water in late spring and summer and during dry periods as in-lieu supply for existing groundwater users. This operation increases the use of available groundwater storage capacity by employing surface storage as a "regulating" reservoir for short duration capture of surplus flows. Collectively, the integrated storage operation increases water deliveries significantly more than each storage type operated independently.

Figure 15 shows simulated use of the new storage options for integrated surface and groundwater storage operation in the Sacramento Valley (top panel) and San Joaquin Valley (bottom panel). Surface storage helps capture pulses of available supply such as in 1921-1923 and 1993-1999 periods. Water is then transferred from surface storage to supply existing groundwater users, who "augment" groundwater storage by reducing groundwater pumping. This integrated surface and groundwater bank storage operation reduces need for surface storage capacity while greatly increasing use of underground storage capacity.

Figure 15. Simulated Integrated Use of Sacramento Valley (top) and San Joaquin Valley (bottom) Surface and Groundwater Bank Storage with New Delta Conveyance, CalLite with historical climate



Integrating Surface and Groundwater Storage and Improving Conveyance

To show how other facility improvements, such as improved conveyance, affect the use of new storage capacity, we evaluated the new storage options with improved Delta conveyance and a more integrated operation of the surface and groundwater storage options. Table 6 summarizes storage capacity utilization for different combinations of surface and groundwater storage and Delta conveyance and integrated storage operations.

Use of additional Sacramento Valley storage capacity is less affected by Delta conveyance assumptions. Nearly 2 maf of new surface storage and 2 maf of new groundwater storage located in the Sacramento Valley can be utilized. However, use of additional storage located in the San Joaquin Valley is highly sensitive to the Delta conveyance assumptions. Surface storage use is nearly two times higher with new Delta conveyance than with existing Delta conveyance. Additional groundwater bank storage utilization in the San Joaquin Valley is relatively small with existing conveyance and regulations, but increases greatly with improved Delta conveyance. Conveyance and integration affect the ability to make use of storage capacity in different parts of the state.

Table 6. Summary of Maximum Storage Utilization for Different Delta Conveyance and Integrated Surface and Groundwater Storage Combinations, CalLite with historical climate (Values in parentheses are storage utilization computed as the storage use exceeded in only 10 percent of years)

Storage	Existing Delta Conveyance	Integrated SW and GW Operations w/ Existing Delta Conveyance	New Delta Conveyance	Integrated SW and GW Operations with New Delta Conveyance
Sacramento Valley				
Surface Storage	1.8 maf (1.8 maf)	1.8 maf (1.8 maf)	1.8 maf (1.8 maf)	1.8 maf (1.8 maf)
Groundwater	2.0 maf (2.0 maf)	2.0 maf (2.0 maf)	2.0 maf (2.0 maf)	2.0 maf (2.0 maf)
San Joaquin Valley				
Surface Storage	1.2 maf (800 taf)	900 taf (100 taf)*	1.8 maf (1.5 maf)	1.4 maf (1.0 maf)
Groundwater	< 50 taf (<50 taf)	<200 taf (<200 taf)	<200 taf (<100 taf)	1.1 maf (1.0 maf)
Total				
Total Storage Utilization	5.0 maf (4.6 maf)	4.9 maf (4.1 maf)	5.8 maf (5.4 maf)	6.3 maf (5.8 maf)

*When SAC storage is integrated with SJV storage, excess Delta supply that would have been stored in SJV is diverted to SAC storage. Existing conveyance limits opportunities to use BOTH surface storage options effectively.

Performance of Storage Programs for Water Delivery and Ecological Metrics

So far our results have only reported storage utilization, but storage utilization is not a fundamental objective for a water system. More useful measures of the value of storage are based on how much additional water it provides for beneficial uses. Accordingly, we turn next to more relevant metrics of water delivery and ecological performance.

Each storage option also was evaluated for improvements in water delivery and ecological metrics. Figure 16 shows a summary of the increases in SWP and CVP water deliveries south of the Delta for each storage and conveyance case. The left group of columns show simulated delivery improvements for the different storage options with existing Delta conveyance. The expanded Sacramento Valley storage increases water deliveries by 200 to 400 taf/yr, with larger increases in the driest years. Expanded San Joaquin Valley surface storage capacity shows benefits of up to 100 taf/yr while delivery improvements are very small with San Joaquin Valley groundwater storage with existing Delta conveyance.

Combining storage expansion options with improved Delta conveyance, shown in the group of columns to the right, increases deliveries by 600 to 900 taf/yr beyond the individual storage options. Integrating the operation of surface and groundwater storage options together with improved Delta conveyance improves water deliveries by of over 1 maf/yr.

These increases in water deliveries were achieved while maintaining ecological flows (as defined) in the Sacramento River and Delta. Critical storage levels in Shasta Lake and Folsom Lake, which indicates coldwater pool management capability, were similar in most storage simulations. Simulations with expanded Sacramento Valley storage generally made small improvements in the frequency of achieving these critical cold water storage levels in Shasta Lake (less than 5 percent increases). Future work could refine operations modeling with an aim to achieve greater upstream cold water storage protection with limited impacts on water delivery.

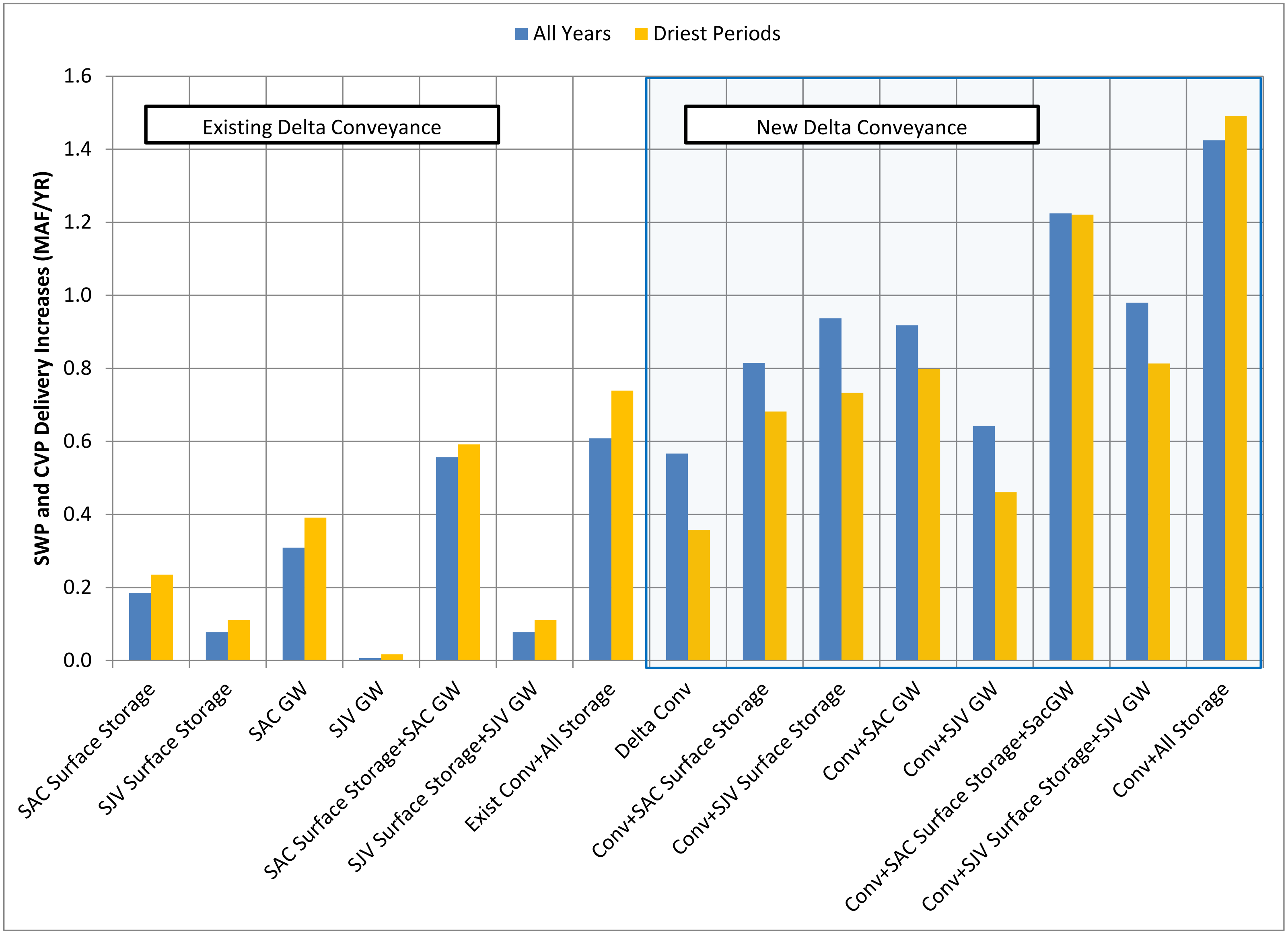
For convenience and ease of interpretation in this pilot study, water delivery improvements are analyzed and reported in terms of how much additional water might be supplied to known demands, and in the case of Figure 16, demands south of the Delta. Portions of these additional water supplies also could be provided to environmental needs such as Delta outflows and Central Valley wetlands. Future work, beyond the scope of this study, could investigate more fully the possibilities for additional storage to provide water supplies for environmental needs.

Expanding an Integrated Approach

For broader application, designed to explore and design particular portfolios of storage and other actions, it would be desirable to expand this type of analysis to include several other aspects of integration. These additional features would include:

- Examination of anticipated or likely climate changes
- Identification and evaluation of ecological implications of surface and groundwater management actions
- Additional conveyance and groundwater alternatives
- Evaluation of local groundwater banking opportunities
- Water demand management activities
- Economic costs and values of alternatives
- Ecological implications of various storage alternatives.

Figure 16. Average South of Delta Water Delivery Increases for Various Storage Options and Delta Conveyance Assumptions: *More integrated water management greatly increases Water Deliveries for Various Storage and Conveyance Conditions*, CalLite with historical climate



Insights from an Integrated Approach

A systems-based approach can offer new insights for understanding the value and limitations of water storage and for developing future storage strategies in the context of a more comprehensive water management vision. The major insights from our pilot simulation analysis include:

- Benefits of expanded storage depend strongly on its location and connections with the integrated system.
- Additional surface and groundwater storage in the Sacramento Valley, when operated as integrated storage units, can increase water deliveries and improve coldwater pool conditions.
- Additional surface storage in the San Joaquin Valley can improve dry-year water deliveries, but it is only effectively utilized with improved Delta conveyance.
- Additional groundwater storage helps improve seasonal and long-term water availability and drought protection in the Sacramento Valley and San Joaquin Basin.
- Integrating storage operations greatly improves benefits north and/or south of the Delta for short-term water deliveries and long-term drought reliability.
- Large scale in-lieu groundwater banking is more productive if planned and operated in coordination with surface storage to regulate wet period surface supplies to improve dry period groundwater deliveries. Peak seasonal flows alone are too infrequent and short in duration to provide much groundwater recharge benefit. Surface storage provides regulating capacity to improve groundwater recharge. Some investment in surface storage can expand groundwater recharge, within limits of water availability.
- Total surface and groundwater storage capacity increases of 2 to 4 maf in the Sacramento Valley and 1 to 2.5 maf in the San Joaquin Valley can be utilized to provide additional water deliveries. New storage capacity beyond these levels seems unlikely to substantially increase water deliveries.
- System-based integrated approaches allow for multiple purposes and highlight their tradeoffs and synergies of different types of projects, particularly groundwater and surface water storage possibilities.
- Groundwater recharge seasons and rates significantly constrain large scale use of in-lieu recharge for agricultural pumpers. Some additional recharge can occur using surface storage as a forebay for delivering water for in-lieu recharge. Further analysis of potential aquifer recharge system-wide, such as considering winter recharge over agricultural lands and artificial recharge, might provide additional local and regional opportunities to make use of existing groundwater storage capacity.
- These simulation results agree well with similar results from less constrained optimization modeling.

Conclusions

Both surface water and groundwater storage are important for water management in California. As a result of passage of Proposition 1, the 2014 Water Bond, the potential and value of additional water storage in California is an area of vigorous discussion. This paper reviews the roles of storage in California's integrated water system and provides some insights from a systems-based approach for evaluating additional storage capacity. The pilot study in this paper is a "proof-of-concept" demonstration of a systems-based approach, which yields insights on storage opportunities and challenges. Further application of such a systems-based approach will further improve understanding of surface and/or groundwater storage as part of addressing California's larger water management challenges.

Overall, the pilot study results indicate that integrated water infrastructure programs are likely to significantly outperform individual projects in achieving multiple water management objectives, including water supply reliability, healthy ecosystems, and flood protection. A system analysis approach will best identify specific storage and other projects to meet these objectives.

Several additional high-level conclusions can be drawn from the results:

1. In California, additional surface water and groundwater storage capacity will be more effective if planned, designed and operated as components of an integrated state-wide system. Additional surface storage and groundwater storage capacity and locations must be integrated with other conveyance, operating, and conservation decisions and policies to serve California's diverse present and changing water needs.
2. A systems-based analytical approach, where new projects are evaluated in conjunction with re-operation of many parts of the state water system, can identify promising and effective actions to achieve multiple objectives.
3. Conveyance limitations in the Delta are a major impediment to the state's ability to achieve its "co-equal" water management goals of reducing reliance on the Delta as a water supply source and conserving habitat and species in the Delta, and the ability to make full utilization of surface water and groundwater storage capacity. Improving Delta conveyance and integrating operations greatly increase the additional deliveries possible per unit of additional storage capacity.
4. There is some potential for expanded storage to improve cold water pools and flows for fish in dry periods.
5. No more than 5 to 6 maf of expanded groundwater and surface water storage capacity (2 to 4 maf north and 1 to 2.5 maf south of the Delta) can be effectively utilized in the Central Valley for large-scale water delivery. However, the economic and environmental impacts and benefits of such expansions might not justify the costs of such projects.
6. Storage is one component of a very integrated water system, and integrated water management requires that water supply, water demand, and system improvements be considered together.

Recommendations

Water storage and infrastructure re-configuration are topics of active and animated discussion in California, particularly during the current drought. This study suggests several promising actions for stakeholders and agencies interested in integrated performance-oriented analysis of potential storage and other infrastructure changes for California's water supply system.

1. Studies examining water storage, and water management more generally, should explicitly consider potential for integrating surface and groundwater storage, as well as conveyance and water demand management. Given the demonstrated benefits of integrated management, a transformation is needed in how agencies and stakeholders think about conducting water infrastructure studies. Recent state groundwater legislation could be instrumental in supporting such coordination at regional and local levels.
2. There is a need for more explicit and proactive consideration of potential ecological benefits of surface and groundwater storage in studies of water management infrastructure and operations. Active engagement of environmental advocates and wildlife resource agencies in shaping the exploration and development of infrastructure and operations proposals is critical for strengthening the ecologic function of future projects.
3. Recent studies of water management infrastructure have not proceeded in timely, transparent, collaborative, or cost-effective ways. It may be time to develop an independent, alternative entity with the business and technical capability to bring together state and federal regulatory and project agencies with local benefitting agencies and independent and academic technical expertise to conduct more systematically integrated studies of water infrastructure and operations for multiple purposes.

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Appendix A
Pilot Study Storage Options and Assumptions

Introduction

To illustrate elements of the proposed systems-based approach, a pilot study of storage options in the Central Valley has been developed using the CalLite water resources model. The pilot analysis considers two simplified surface storage and two groundwater storage configurations in the Sacramento and San Joaquin Valleys, and illustrates the potential range of benefits that could be derived from the integration of storage features under alternative system assumptions. Various combinations of surface and groundwater storage options combined with Delta conveyance assumptions were evaluated to illustrate the dependence of the storage operation and benefits on the ability of the conveyance system to integrate such new features.

CalLite Water Resources Systems Model

The CalLite water resources system model was used to evaluate the operation and integration of potential storage options. The CalLite model is a screening model of the Central Valley intertied water resources system and includes the major rivers and water management features in the Sacramento Valley, San Joaquin Valley, and Tulare Lake watersheds (Reclamation 2014b). Operation of all major SWP, CVP, and local project reservoirs, Delta diversion facilities, and the California Aqueduct and Delta Mendota Canal are explicitly simulated in the CalLite model. The CalLite model includes dynamic accounting of flow-salinity relationships in the Delta, Delta requirements under various regulatory conditions, and dynamic allocation decisions for water deliveries to municipal, agricultural, and environmental uses. Groundwater is dynamically integrated with the surface water system in the CalLite model through the inclusion of groundwater basin elements that transmit flow to and from the surface water system.

The current version of the CalLite model utilizes projected water demands based on planning area estimates of population, land use, and irrigated acreage through 2100. The socioeconomic assumptions are generally consistent with those described as *Current Trends* scenario in the 2013 California Water Plan. Hydrology assumptions were based on a repeat of historical 1915-2003 hydroclimate with future projected land use assumptions. The assessment of future demands and upper watershed river flows were derived from WEAP modeling using the socioeconomic and climate assumptions.

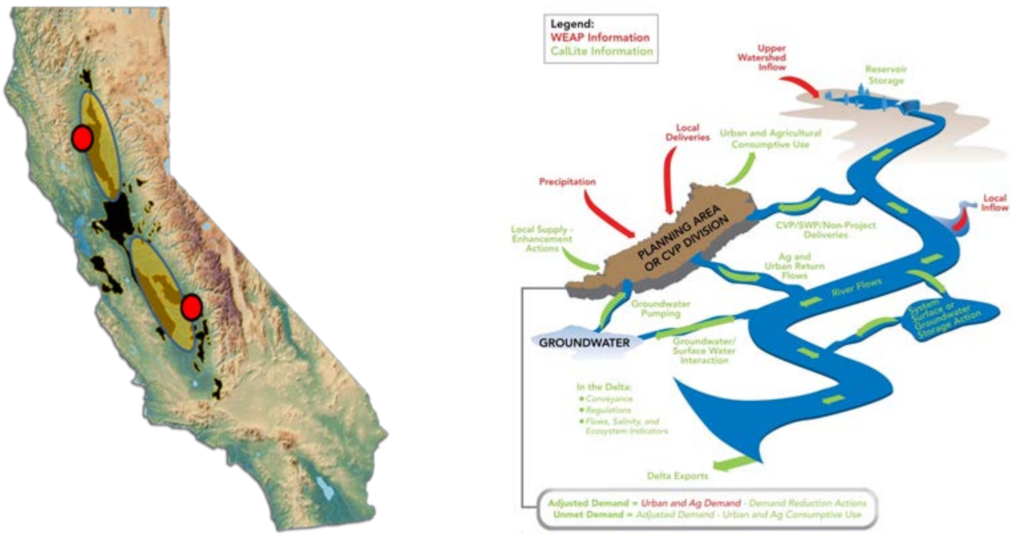
For this evaluation, the CalLite model was improved to include new offstream surface storage reservoirs and groundwater storage banks in the Sacramento Valley and San Joaquin Valley. Groundwater storage capacity and the ability to recharge and extract water from the aquifers was developed from California's C2VSIM groundwater-surface water system model (Brush et al. 2013) analyses and simplified for integration in the CalLite model simulations. These new storage features were simulated as being integrated with the SWP and CVP system in the Central Valley. Assumptions related to these new storage features are included in the following section.

Storage Options and Assumptions

The pilot study evaluated the addition of up to four new storage options integrated into the Central Valley water resources system. Each storage facility was assumed to be sized to permit up to 2 maf of storage capacity. One surface storage facility and one groundwater facility were located north of the Delta (in the Sacramento Valley), and one each south of the Delta (in the San

Joaquin Valley). The storage facilities were analyzed as integrated facilities within the intertied state and federal water system. For this pilot study, the storage configurations are operated for both water supply and environmental flows. Figure A-1 depicts the general location of the surface and groundwater storage programs and the integrated hydrologic system included in the CalLite model.

Figure A-1. General Location of the surface and Groundwater Storage Programs and the Integrated Hydrologic System included in the CalLite Model



The pilot study's storage option assumptions are summarized below:

<u>New Sacramento Valley Surface Storage</u>

- Up to 2 maf of new offstream storage located in the Sacramento Valley
- Sacramento River diversion physical conveyance of up to 6,000 cfs during November through March
- River diversion (reservoir fill) permitted only during November through March high river flow periods and after downstream environmental flows are satisfied
- Releases from storage back to the Sacramento River for SWP and CVP integration were limited to 3,000 cfs and only when either Oroville storage fell below 2.2 maf or Shasta storage fell below 3.0 maf. The Oroville and Shasta storage triggers were used as surrogate indicators when the SWP and CVP upstream storage operations would most greatly benefit from additional supply.
- Release from storage to meet local Sacramento Valley demands was limited to 1,500 cfs during April through October

<u>New Sacramento Valley Groundwater Storage</u>

- Up to 2 maf of groundwater storage in the southern end of the Sacramento Valley

- Sacramento River diversion physical conveyance of up to 2,000 cfs during November through March to provide "in-lieu" supply to overlying groundwater users. This is the "in-lieu" groundwater banking operations. Up to 75% of overlying groundwater demands assumed could be provide with "in-lieu" surface water when available.
- Groundwater bank was allowed to accrue water only when overlying demand could be supplied by alternative surface water supply.
- Releases from storage back to the American River or Sacramento River during July through August to support SWP and CVP integration were limited to 3,000 cfs and only when either allocation to water delivery contractors fell below 70%.

<u>New San Joaquin Valley Surface Storage</u>

- Up to 2 maf of new offstream storage located in the San Joaquin Valley and connected to the California Aqueduct and/or Delta Mendota Canal conveyance
- Diversion to storage required available supply and conveyance capacity at the Delta diversion facilities (existing and proposed)
- Diversion to new storage only permitted with surplus water after all Delta flow requirements were satisfied, existing San Luis Reservoir was filled, and SWP Article 21 demands were met.
- Releases from new storage to the California Aqueduct or Delta Mendota Canal were provided (if water was available in storage) July through August when the allocation to water delivery contractors fell below 70%.

<u>New San Joaquin Valley Surface Storage</u>

- Up to 2 maf of groundwater bank storage located in the San Joaquin Valley and connected to the California Aqueduct and/or Delta Mendota Canal conveyance
- Diversion to storage required available supply and conveyance capacity at the Delta diversion facilities (existing and proposed) to provide "in-lieu" supply to overlying groundwater users. This is the "in-lieu" groundwater banking operations. Up to 75% of overlying groundwater demands assumed could be provide with "in-lieu" surface water when available.
- Diversion to the groundwater bank only permitted with surplus water after all Delta flow requirements were satisfied, existing San Luis Reservoir was filled, and SWP Article 21 demands were met.
- Releases from new storage to the connected users of the California Aqueduct or Delta Mendota Canal were provided (if water was available in storage) July through August when the allocation to water delivery contractors fell below 70%.

<u>Delta Conveyance Assumptions</u>

Two sets of assumptions were included depending on the scenario:

1. Existing Delta conveyance facilities and regulatory requirements
2. Proposed future north delta conveyance of up to 9,000 cfs diversion with bypass flows as assumed under the Bay Delta Conservation Plan, and existing regulatory requirements

Integrated Surface-Groundwater Storage Operations

In scenarios in which new surface storage was operated conjunctively with new groundwater banks, the surface storage was used as the primary storage location for available surface supply. Water was then released from surface storage to meet the overlying groundwater demands through and "in-lieu" operations. Essentially, the surface storage was operated as a regulating reservoir to maximize the benefits of the in-lieu groundwater operation.

Limitations

The CalLite storage options and scenarios developed as part of this pilot study should be considered conceptual in nature, and were developed to demonstrate the value of a systems-based approach toward storage evaluations. Specific storage sites, connectivity with existing and proposed conveyance, and access to additional supplies will significantly influence the operations and benefits of storage features. This pilot study should be viewed as demonstrative of the types of further evaluations that may be undertaken to better inform the role of storage, but more detailed evaluations would necessarily need to be performed to refine any operations or estimates derived from this pilot study.

Item No. 2

INFORMATION ITEM
December 2, 2019

TO: **Planning & Operations Committee**
(Directors Yoo Schneider, Dick, Tamaribuchi)

FROM: **Robert Hunter, General Manager**

Staff Contact: Karl Seckel

SUBJECT: **America's Water Infrastructure Act (AWIA) Status Update**

STAFF RECOMMENDATION

Staff recommends the Planning & Operations Committee receives and files the report.

COMMITTEE RECOMMENDATION

Committee recommends (To be determined at Committee Meeting)

DETAILED REPORT

WEROC launched an effort to facilitate a joint RFP and contract with participating WEROC member agencies to address the new requirements of America's Water Infrastructure Act (AWIA). On October 23, 2018, Congress signed into law the American Water Infrastructure Act (AWIA) (S.3021, Law 115-270). Per Section 2013 of Title II, the AWIA requires utilities to conduct a Risk and Resilience Assessment (RRA) of their community water systems and develop a corresponding Emergency Response Plan (ERP). March 31, 2020, for systems serving the population of 100,000 or more.

- 25 Agencies participated in the Phase 1 Crosswalk Compliance. After the completion of Phase I, two agencies decided to not continue in the MWDOC AWIA Contract and do the work for AWIA compliance on their own by the EPA designated dates. These agencies are Seal Beach and Yorba Linda Water District (East Orange County Water District is still considering their options, but may also drop out). There is a contingency if these agencies seek to re-join the project at a later date.

Budgeted (Y/N): n/a	Budgeted amount: n/a	Core ✓	Choice __
Action item amount: n/a	Line item: n/a		
Fiscal Impact (explain if unbudgeted): n/a			

- All Phase 1 Crosswalks have been developed and provided to agencies. Some discussion and editing is still occurring. The crosswalks remain a draft as agencies work through the Phase 2 and Phase 3 processes. have gone through the process to get governing board or council approval to participate in the next phases
- Twenty two (22) agencies will participate in the Phase 2 Risk and Resilience Assessments and Phase 3 Emergency Response Plans and have gone through the process to get governing board or council approval to participate.
- HSG assistant project managers began conducting the first Risk and Resiliency Assesment Workshops on October 29. The workshops are two-day events with key staff from each of the agencies to complete the asset and threat characterization. A second two-day workshop will complete the consequence and vulnerability analysis. The combination of these workshops will provide the basis for a completed RRA. Work is proceeding with the first workshops for the agencies while scheduling of the second workshops are underway.
- All Group 1 Agencies (listed below), which are the agencies that serve a population of 100,000 or more, have completed their first Risk and Resilience Assessment Workshops (RRA). These workshops included discussions of Critical Assets, Threats, creation of Threat Asset Pairs, Vulnerabilities, and Consequences.

Municipal Water District of Orange County
Irvine Ranch Water District
Santa Ana, City of
South Coast Water District
Huntington Beach, City of
Garden Grove, City of
Moulton Niguel Water District
Santa Margarita Water District
Fullerton, City of
Orange, City of
San Juan Capistrano, City of

- Irvine Ranch Water District has completed its second RRA Workshop and all the other Group 1 cities/water districts have scheduled their second workshops for early December.
- Last week, MWDOC had its first RRA Workshop and the following staff members were present:
    - Patrick Dinh, Cathy Harris, Charles Busslinger, Jeff Stalvey, Karl Seckel, Daniel Harrison, Chris Lingad, Hilary Chumpitazi, Rob Hunter, Chris Lindad and Leslie Schwene
    - Since MWDOC is more unique with less physical assets than the other agencies in the AWIA project, discussions were centered around the security of the MWDOC facility and South EOC, cyber systems, critical employees and the role of MWDOC/WEROC for its member agencies.

- Leslie Schwene, a part-time employee hired to assist with the AWIA Coordination, has been attending various RRA Workshops for different cities and water agencies to learn, participate, and support HSG in the RRA Workshop process. Additionally, her duties include monitoring and reviewing monthly invoices from HSG and working with the Accounting department to ensure all is correct, coordinating with the consultant team for workshops and agency correspondence as needed, collecting and organizing signed agreements for Phase 2 and 3 of the project, and monitoring overall project progress.

Item No. 3

INFORMATION ITEM
December 2, 2019

TO: **Planning & Operations Committee**
(Directors Yoo Schneider, Dick, Tamaribuchi)

FROM: **Robert Hunter, General Manager**

Staff Contact: Karl Seckel

SUBJECT: **Santa Ana Regional Water Quality Control Board (Santa Ana Water Board) Recommendations Regarding the Poseidon Regional Board Permits and Ocean Plan Amendment Compliance**

STAFF RECOMMENDATION

Staff recommends the Planning & Operations Committee receives and files the report.

COMMITTEE RECOMMENDATION

Committee recommends (To be determined at Committee Meeting)

DETAILED REPORT

The Santa Ana Regional Water Quality Control Board (SARWQCB) informational meeting to receive input regarding the terms and conditions for the NPDES permit and to determine compliance with the Ocean Plan Regulations will be held on Friday December 6 in the City of Huntington Beach Council Chambers, 2000 Main Street. This meeting is only an informational meeting to take input on the DRAFT permit and conditions. It is expected that the actual permit will be considered and issued in early 2020. Then Poseidon would seek its final permits from the California Coastal Commission.

Staff has preliminarily examined the December 6 documents (28 page report, 495 pages with all attachments). The following should be noted:

Budgeted (Y/N): n/a	Budgeted amount: n/a	Core ✓	Choice __
Action item amount: n/a	Line item: n/a		
Fiscal Impact (explain if unbudgeted): n/a			

The recommendation from the Santa Ana Water Board is to direct staff to solicit comments on the tentative Order and draft Water Code determinations, prepare written responses to comments received and bring an appropriately revised Order and Water Code determination back to the Santa Ana Water Board for consideration at a future public hearing.

Major Findings by the Santa Ana Water Board

Following are the major findings by the Santa Ana Water Board:

1. The Ocean Plan requires that alternative sites be evaluated to determine the best site feasible to minimize the intake and mortality of all forms of marine life. Based on the site criteria, the proposed Facility location in Segment 1 which is north of the Santa Ana River and more specifically at the AES Huntington Beach Generating Station (HBGS) in the City of Huntington Beach, it is Santa Ana Water Board's staff recommended best site feasible for the Facility location.

2. Santa Ana Water Board staff reviewed Poseidon's analyses, including their supplemental hydrogeological modeling, and determined that Poseidon has demonstrated that subsurface intakes (e.g., seafloor infiltration galleries and slant wells) are technically infeasible for the proposed annual average intake volume of 106.7 MGD of seawater based on hydrogeological conditions at the proposed site and alternative sites.

3. The NEED for the project is included in a number of Urban Water Management Plans, including that of MWDOC. They did, however, note that MWDOC recently released its 2018 reliability study that projects water supply and demand in Orange County through the year 2050 and compares local projects that can meet the forecasted water demands. The proposed Poseidon project is among the local projects that were compared and ranked last based on system reliability and supply reliability metrics. The purpose of the study, however, was not to determine which projects should be implemented; rather, it was intended to provide information to local decision makers charged with choosing local projects. While there may be more cost-effective projects to meet water supply needs in Orange County, the proposed Project is among the potential projects that local suppliers can choose to pursue to meet water demand. The cost of the proposed Facility's water is a factor that water suppliers will likely consider, but it is not an issue that falls within the guidelines set forth in the Ocean Plan for the determination of need for desalinated water.

4. A consultant to the Santa Ana Water Board, Dr. Roberts, recommended a different diffuser design to meet the Ocean Plan requirement to maximize the dilution and minimize the brine mixing zone thereby reducing the mortality to marine life. Subsequently, Poseidon revised the diffuser design using the methodology recommended by Dr. Roberts and is proposing a fourteen-port linear diffuser to be installed at the end of the HBGS's current outfall to discharge the effluent brine. This diffuser design will result in less shear and therefore, reduced impacts to marine life.

5. The specific impact to marine life is calculated by way of the Empirical Transport Model/Area of Production Foregone (ETM/APF) methodology to translate marine life

mortality into the number of acres of marine life productivity that will need to be mitigated to offset impacts to marine life from the construction and operation of the proposed desalination Facility. ETM is a method for determining the spatial area where organisms are at risk of entrainment by the proposed Facility (also known as the source water body).

The approach narrowed down the seven potential sites to three sites: Station E - Poseidon's proposed intake location; Station U2 – located 4 kilometers upcoast of Station E; and Station D2 – located 4 kilometers downcoast from Station E. The results of this analysis demonstrated that Stations U2 and D2 would result in lower marine life mortality than Poseidon's proposed Station E.

Santa Ana Water Board staff then worked with Poseidon to evaluate other factors as required by the Ocean Plan – technological, economic, and social factors to determine site feasibility of siting the intake at Station D2, U2 or Poseidon's proposed Station E. Based on considerations of technological, economic, and social factors and the additional time that would be needed to move the surface intake for the proposed Facility to an alternative location at Station U2 or D2, the Santa Ana Water Board staff recommends that the existing surface intake and discharge structures at the AES HBGS (located adjacent to Station E) be used for the proposed desalination facility and upgraded as required by the Ocean Plan (i.e., installation of 1-millimeter wedgewire screen to the intake structure and installation of a multiport diffuser to the discharge structure).

The proposed mitigation ratio was applied to the ETM/APF calculations for Station E that were reviewed and approved by Dr. Raimondi, the neutral third-party reviewer. The amount of mitigation that will be required once the mitigation ratio is applied to the area impacted (APF) by the proposed Facility is as follows:

Impact	**Impact APF (acres)**	**APF to be mitigated (acres)***
Seawater intake	161.2	34.3
Brine Discharge (shearing)	258.1	54.8
Brine Mixing Zone	1.09	0.19
Intake Construction	0.88	0.15
Diffuser Construction	0.15	0.03
Total	**421.42**	**89.47**

*mitigation ratios applied are based on the relative biological productivity of the impacted habitat and the mitigation habitat. The ratio for out-of- kind mitigation for soft-bottom, open water species (coastal taxa) shall be 1 acre of mitigation habitat for every 5.8 acres of impacted habitat (1:5.8). The ratio for in-kind mitigation (estuarine species) shall be one habitat for every one acre of impacted habitat (1:1).

Based on Santa Ana Water Board staffs' estimation of marine life mortality, the required acres needed to mitigate for marine life mortality impacts related to the Facility's construction and stand-alone operations is 89.47 acres (see summary table above). To fulfill the required mitigation acreage, Poseidon proposed in their Marine Life Mitigation Plan (MLMP) to conduct maintenance dredging of the ocean inlet at

Bolsa Chica to support the Bolsa Chica Lowlands Restoration Project in order to maintain full tidal flow within the Bolsa Chica wetlands. The inlet channel has historically shoaled and filled with sand limiting tidal exchange between the ocean and the wetlands.

Maintenance dredging of the inlet will provide essential tidal connectivity between the wetlands and the Pacific Ocean. In addition, dredging will help maintain the existing wetland system as well as support restoration and enhancement activities. The maintenance dredging of the ocean inlet will be done as needed to meet performance standards specified in the MLMP.

Santa Ana Water Board staff determined that the inlet maintenance dredging would be considered a “preservation” form of mitigation, not “expansion,” “restoration” or “creation” as is required by the Ocean Plan. The proposed maintenance dredging alone would only preserve the already existing habitat at Bolsa Chica.

Therefore, to be in compliance with the Ocean Plan, Santa Ana Water Board staff have worked extensively with Poseidon to ensure that the best available mitigation project feasible includes compliant restoration components. There are several areas within Bolsa Chica where Poseidon has proposed restoration activities: Fieldstone Property (Cell 46, and Cell 42 of the Bolsa Chica Lowlands Restoration Project). The Fieldstone property consists of approximately 12 acres of dry, barren salt pans, with marsh and subtidal habitat. Within this property, the discharger proposes to restore approximately 4.5 acres of subtidal and tidal wetlands in addition to upland restoration. At several sites within Cell 46 and 42, oil pads and roads will be removed, and the areas restored to upland habitat. The individual sites for these activities are scattered additional restoration.

For these restoration projects to succeed, Poseidon must make improvements to the water circulation within the Muted Tidal Basins in Bolsa Chica. The circulation improvements constitute enhancement activities, which is considered a type of restoration, but most importantly, based on input from Resource Agency staff (National Marine Fisheries, Coastal Commission and State Lands Commission), these improvements are required for the restoration projects to be fully successful.

Poseidon has not fully developed detailed descriptions of the restoration components of their proposed mitigation plan in the MLMP that has been submitted. The full development of the restoration components requires additional studies and information that are not currently available. Therefore, Santa Ana Water Board staff recommends that the Water Code section determination be conditioned on the Board’s approval of supplemental plans submitted by Poseidon in accordance with the Marine Life Mitigation Plan Schedule included in Attachment K to the tentative Order. Provided that Poseidon satisfies the requirements of Attachment K, the mitigation at the Bolsa Chica Lowlands Restoration Project would provide the mitigation acreage identified below.

Preservation of the Full Tidal Basin via inlet maintenance dredging	108 acres
Restoration of the Fieldstone property to subtidal habitat	4.5 acres
Restoration of the Oil Pads to subtidal habitat	1.2 acres
Enhancement of water circulation within the Muted Tidal Basins	15 acres
Total	**128.7 acres**

Total Bolsa Chica Mitigation Acreage

It is Santa Ana Water Board staff's position that if Poseidon Water successfully implements the above components, they will have adequately mitigated for the construction and operation of the Facility over the 30-plus year life-span of the Facility.

6. Water Code sections also authorize the Santa Ana Water Board to establish monitoring, inspection, entry, reporting, and recordkeeping requirements. The tentative Order specifies a Monitoring and Reporting Program in Attachment E, which includes the following components: influent monitoring, effluent monitoring, toxicity testing and receiving water monitoring.

7. Subsequent to the certification of the 2017 FSEIR, Poseidon made modifications to the diffuser design to comply with Water Code sections and the Ocean Plan. The changes to the diffuser do not involve new significant environmental effects or a substantial increase in the severity of previously identified significant effects that would require the preparation of a subsequent environmental impact report under CEQA Guidelines section 15162. As such, an addendum to the 2010 FSEIR and the 2017 FSEIR is the appropriate documentation to address the changes to the diffuser design.

The link below is to the Agenda only (4 pages):
https://www.waterboards.ca.gov/santaana/board_info/agendas/2019/12-06-2019/R8-AA_12-06-19_English.pdf

The line below is for item 9, NPDES Permit Renewal of the Proposed Huntington Beach Desalination Project, 495 pages:
https://www.waterboards.ca.gov/santaana/board_info/agendas/2019/12-06-2019/Item_9.pdf

ENGINEERING & PLANNING	
Doheny Ocean Desalination Project	On June 27, 2019 the SCWD Board certified the Final Environmental Impact Report (FEIR) for the Phase I Local Doheny Ocean Desalination Project, which would produce up to 5 million gallons per day (MGD) of new, drinking water supplies for the area. SCWD subsequently filed its Notice of Determination and is beginning the permitting process with various permitting agencies. On July 11, 2019 SCWD's Board adopted a resolution pursuing a second year (round) of the USBR WaterSMART Desalination Construction Program grant funding. SCWD is eligible to receive a cumulative total of $20 million for the Project from USBR. Approximately two to six awards are expected to be made by USBR with up to $12 million available in this round. The recipient must provide at least 75% of the total project costs. Reclamation has recently indicated that an initial $8.3M is still with Congress and will be part of a Federal budget approval. SCWD efforts have been successful and AB 1752 was signed into law on October 3, 2019, clearing the way for a DBO award using SRF funding. On October 23, 2019 the US EPA invited SCWD to submit a loan application for a Water Infrastructure Finance and Innovation Act (WIFIA) low interest loan in the amount of $60 million for the Doheny Ocean Desalination Project. On October 30, 2019, South Coast held a workshop on a Peer Review Cost Estimate for the Doheny Desal Project. Rich Svindland, of California American Water (CalAm), who helped develop the 6.4 MGD Monterey Ocean Desal Project using slant well technology, completed a peer review cost estimate for the Doheny Ocean Desal Project. A workshop was held on October 30, 2019 to present the Peer Review by CalAm based on their experience in developing and **<u>bidding</u>** a project in Monterey (that plant has not been constructed due to permitting and legal issues). The CalAm presentation and review of the previous Doheny Desal cost estimate by GHD indicated some differences in capital and operating costs including a higher level of staffing for the plant as suggested by CalAm. Overall the cost differences resulted in estimated increased costs: • Capital costs were estimated at 5.4% higher • O&M costs were estimated at 15.8% higher • Overall, the unit cost of water increased from $1556 per AF to $1805 per AF, an increase of $249 per AF, an overall increase of about 16.0% On November 14, South Coast WD held a workshop on the risks of slant well technology. Geoscience Support Services provided the bulk of the technical information on the use of vertical wells compared to slantwells. The main

	problems with vertical wells in a small basin such as the coastal portion of the San Juan Groundwater basin are: • The potential for well screen blockage due to minerals and biofouling because the well screens do not stay submerged in water 100% of the time compared to slantwells. • Lost water production due to declining groundwater levels. • Potential interference from other nearby wells. • Lower production due to aquifer thickness. The main disadvantage of slantwells is: • The cost of maintenance is high because the rigs to pull and replace pumps is on a slant. • The unknown regarding the concentrated iron and manganese laden water found during the pilot testing. Overall, the Geoscience report recommended slantwells for this type of application. Not all in attendance concurred as SMWD General Manager Dan Ferons suggested additional groundwater basin exploration with respect to the bedrock high transmissivity, getting a third independent hydrogeological opinion on the best approach for the lower basin coastal area and potentially installing one vertical well and one slantwell for test purposes. Possibly the biggest issue discussed at the meeting was the apparent South Coast WD Board opinion that 5 mgd was too much capacity for South Coast WD needs and without other partners, they may consider a plant size as small as 2.5 mgd without the oversizing to protect the potential for an ultimate 15 mgd project. The use of excess recycled supplies potentially to be blended with ocean supplies was also discussed with the Latham wastewater plant in near proximity to the Doheny Desal Project. **<u>Next Steps by South Coast WD:</u>** 1. Look for partners 2. Project Delivery – SCWD has begun working with Hawkins Delafield and Wood, and GHD on development of several documents for a DBO contract including; Request for Statement of Qualifications (SOQ) for potential bidders, contract documents, and a RFP package. 3. High Level Schedule (has slipped a bit due to the Regional Board schedule) a. Environmental permitting — Late Summer 2020 b. DBOM Contract Develop — Early 2020 c. DBOM Contract Award — Early 2021

	d. Construction Early 2023
MET 2019-20 Shutdown Schedule	MWDOC staff have held many meetings with MET and MWDOC member agencies since July 2019 to review the MET 2019-2020 Shutdown Schedule. One of the proposed shutdowns involves the complete shutdown of the Diemer Water Treatment Plant. MWDOC staff have been working with potentially affected agencies and MET to see what options are available to accommodate a Diemer shutdown; given the State Water Board's intention to reduce PFOA & PFOS Response Level (RL) triggers, and that action's resulting impacts to groundwater pumping in OC. MET also has a West Orange County Feeder shutdown and a shutdown to work on a specific Anaheim A-6 connection to replace valves and a leaking venturi meter. South Coast has a shutdown of the Joint Transmission Line in December that could wrap into early January. Buena Park has several wells out of service for maintenance/repairs. The timing for the PFAS Response level is unknown. All of these items have made this one of the most, if not the most, difficult year for shutdown discussions with our agencies. As recently as Friday November 22, MWDOC met with EOCWD and held discussions with Buena Park, South Coast WD and MET. Most recently, MWDOC has requested MET switch the order of the shutdowns in January to hold the West Orange County Feeder in early January (assuming Buena Park can get ready in time) and to hold the Diemer shutdown later in January. The West Orange County Feeder may have to be moved again. MET has also indicated they would like to hold a second Diemer shutdown in March (assuming PFAS lower Response Levels have not been adopted) to complete their work. This may be the last time MET will be able to shut down the Diemer Plant for the next 4 to 5 years depending on how fast PFAS treatment can be brought on-line. Stay tuned.
SMWD Rubber Dams Project (San Juan Watershed Project)	Santa Margarita WD continues to focus on diversifying its water supply portfolio for south Orange County residents, businesses, schools, and visitors. On June 21, 2019, the San Juan Watershed Environmental Impact Report (EIR) was approved. The original project had three Phases; Phase 1 was three rubber dams recovering about 700 AFY; Phase 2 added up to 8 more rubber dams with the introduction of recycled water into the creek to improve replenishment of the basin for up to 6,120 AFY, and Phase 3 added more recycled water topping out at approximately 9,480 AFY. Under this arrangement, most or all of the production and treatment involved the existing San Juan Groundwater Desalter

	with expansions scheduled along the way to increase production over 5 mgd. Fish passage and regulatory hurdles to satisfy subsurface travel time requirements are presenting some difficulties. SMWD is working with the Ranch on the next phase of development within SMWD and have access to riparian groundwater from the Ranch. Furthermore, they have discovered that the local geology has high vertical percolation rates and sufficient groundwater basin travel time to potentially allow percolation of treated recycled water. SMWD is of opinion that groundwater production and treatment of the groundwater can be initiated in a relatively short time-frame while permitting for percolation augmentation using recycled water from the nearby Trampas reservoir can be added as permitting allows. They believe the new project area may be able to ultimately produce 4,000 to 5,000 AF per year; they believe the original project will continue to be developed for production out of the wells and treatment provided by San Juan Capistrano as the two agencies merge. Ultimate production out of the basin could exceed 10,000 AF per year if all goes well.
MWDOC Workshop with SOC Agencies on Nov 6	MWDOC held a workshop with the SOC Agencies to focus on extension/expansion of the existing South Orange County Emergency Service Program with IRWD and to discuss emergency needs and additional options for emergency water or base-loaded projects for South OC, and to discuss the implications of integrating new local water supply sources into the regional distribution system. The following projects were discussed: • Emergency Services Program Extension/Expansion with IRWD • Groundwater from OCWD and/or other OC Basin Producers • Pump-in to the EOCF#2 • PFAS and Water Quality expectations • Doheny Desal • Poseidon Desal • San Juan Basin IPR • Irvine Lake Storage • Strand Ranch • Peters Canyon Treatment Plant • Oceanus/Camp Pendleton • Reliance on MET Black & Veach and Hazen Sawyer provided input on the need for various water quality investigations prior to bringing new supply projects into operations. Black & Veatch also discussed the work they are conducting for MWDOC on development of a hydraulic model of the regional water system in Orange County as a tool to assist future evaluation of operational strategies. There

	appears to be support from the SOC agencies for such a model that could be accessed by any project proponent. Staff is in the process of distilling information from the meeting and will be bringing back a report to a future P&O meeting.
South Orange County Emergency Service Program	MWDOC, IRWD, and Dudek have completed the initial draft study to determine if the existing IRWD South Orange County Interconnection capacity for providing emergency water to South Orange County can be expanded and/or extended beyond its current time horizon of 2030. Based on the South OC meeting held on April 11, 2019, a spin-off meeting was held with MWDOC, Dudek and operations staff from MNWD and South Coast WD. The purpose was to involve the operators to determine the flexibility of the SOC agencies to deal with variable flows coming from IRWD as outlined in the study. The flows from IRWD to SOC are dependent on the internal demands within IRWD and so will vary from hour to hour and day to day. The discussions indicated that the SOC agencies have considerable flexibility to deal with this situation. The operations group also had several alternatives they thought should be researched by Dudek and MWDOC. Follow-up on these options have been pursued. Dudek participated in the November 6 workshop to re-engage with the SOC agencies on this project. Support from the agencies was expressed to take a small next step to install Variable Frequency Drives at a pump station within IRWD which would be paid for by SOC to help move water from the IRWD system to SOC in an emergency. The Variable Frequency Drives will provide more flexibility to the IRWD operations staff to allow additional water to be sent to SOC while meeting all of the IRWD needs.
Strand Ranch Project	MWDOC and IRWD staff have been exchanging information about the benefits from having water stored in the Strand Ranch Project in case emergencies occur such as Delta Levee Failures that might result in no exports from the Delta until operations are restored. Previously, staff from the two agencies have developed an evaluation process to quantify the benefits of Drought Protection afforded by having water stored in the Strand Ranch Project from having the water classified as “extraordinary supplies” under MET’s Water Supply Allocation Plan. MWDOC staff owe comments to IRWD.
Poseidon Resources Huntington Beach Ocean Desalination Project	The Santa Ana Regional Water Quality Control Board (SARWQCB) informational meeting to receive input regarding the terms and conditions for the NPDES permit and to determine compliance with the Ocean Plan Regulations will be held on Friday December 6. It is expected that the actual

	permit will be issued in early 2020. Then Poseidon would seek its final permits from the California Coastal Commission. Staff has preliminarily examined the December 6 documents (28 page report, 495 pages with all attachments). A report is included in the December 2nd P&O Committee Agenda.
Trampas Canyon Dam and Reservoir	Construction of Trampas Canyon Dam and Reservoir by SMWD, Orange County's largest recycled water reservoir, is on track to be completed in the summer of 2020. The 5,000 AF reservoir will store recycled water in low demand months to provide supplies to SMWD and other agencies in the summer periods. The dam and pipeline phase of the project is 68% complete. The pump station construction contract was award to Kingmen Construction on November 22, 2019 for $3.356 million. Substantial completion of the pump station is anticipated in July 2020.
Benefits of Additional Surface Storage in Southern California	CDM Smith and staff are working on a technical memo that is a spin-off from the 2018 Orange County Water Reliability Study (2018 OC Study). The work will evaluate a conceptualized new MET surface reservoir in terms of overall ability to provide additional supply yield under a number of scenarios. The modeling from the 2018 OC Study will be used to evaluate the use of new storage, the potential yield and the costs of the yield from the reservoir. A full staff report is included in the P&O Committee for Dec 2.
Meetings	
	Charles Busslinger attended the November 12, 2019 San Juan Basin Authority Board meeting. The City of San Juan Capistrano officially gave the required 120 days' notice of their intent to withdraw from the Authority in light of the pending annexation of the City's water and sewer systems by Santa Margarita Water District. The transfer of the water and sewer systems is anticipated in the spring of 2020 and the withdrawal will coincide with the date of the transfer.
	Karl Seckel, Rob Hunter and MWDOC Director Yoo-Schneider met with Interim General Manager Chris Regan for Laguna Beach County Water District Board to discuss upcoming issues over the next several months until such time as they appoint a permanent GM.

Status of Ongoing WEROC Projects
November 2019

Description	Comments
Hazard Mitigation Planning	WEROC is completing follow-up with the 19 member agencies who participated in the 2018 update of the Orange County Water and Wastewater Multi-Jurisdictional Hazard Mitigation Plan. Once all agencies have adopted the plans, MWDOC needs to compile and bind all approval resolutions into an appendix and send it to FEMA. That is the last step for this version of the Hazard Mitigation Plan that is updated every five years.
America's Water Infrastructure Act (AWIA)	Ongoing: WEROC launched an effort to facilitate a joint RFP and contract with participating WEROC member agencies to address the new requirements of America's Water Infrastructure Act (AWIA). On October 23, 2018, Congress Signed into law The American Water Infrastructure Act (AWIA) (S.3021, Law 115-270). Per section 2013 of title II, the AWIA requires utilities to conduct a Risk and Resilience Assessment (RRA) of their community water systems and develop a corresponding Emergency Response Plan (ERP). March 31, 2020, for systems serving a population of 100,000 or more. New Actions: • 25 Agencies participated in the Phase 1 Compliance Crosswalk • It now appears that 22 agencies will participate in the Phase 2 Risk and Resilience Assessment and Phase 3 Emergency Response Plans. • All Phase 1 Crosswalks have been developed and provided to agencies. Some discussion and editing are still occurring. The crosswalks remain a draft as agencies work through the Phase 2 and Phase 3 processes. • HSG assistant project managers began conducting the first Risk and Resiliency Assessment Workshops on October 29th. The workshops are two-day events with key staff from each of the agencies to complete the asset and threat characterization. A second two-day workshop will complete the consequence and vulnerability analysis. The combination of these workshops will provide the basis for a completed RRA. Work is proceeding with the first workshops for the agencies while scheduling the second workshops is underway. • Karl Seckel is working with the participating agencies to obtain approved and executed agreements between MWDOC and member agencies for participation and costs of Phases 2 & 3. • A full report is provided in the P&O committee report.

WEROC Coordination	Daniel attended the California Emergency Services Association conference in Sonoma County. The conference had some great presentations and classes. A few key highlights include FEMA Community Resilience, Geospatial Information Awareness, Early Wildfire Detections, and Notification, etc. Generally these classes provided additional depth of knowledge as it relates to WEROC's mission and making Orange County more resilient to the next disaster. Specifically, Daniel continues to work with SDG&E on Geospatial Information Systems to add water and wastewater Infrastructure so there is a clear understanding of what is actually impacted during PSPS events. Additionally, WEROC continues to coordinate with SDG&E to add all critical sites to priority restoration post-PSPS event. Having been trained as a Terrorism Lisaon Officer Daniel continues to review daily intelligence reports in order to better direct WEROC efforts and inform member agencies to threat trends. WEROC obtained and coordinated an ICS-300 training (intermediate incident command training) on October 15-17 for 40 staff from our member agencies. ICS-300 should be taken by persons serving as command staff, section chiefs, strike team leaders, task force leaders, unit leaders, division/group supervisors, branch directors, and multi-agency coordination system/emergency operations center staff. It's also important as an essential element for NIMS compliance which is tied to grant funds. Janine attended and graduated from this great training furthering her knowledge in FEMA emergency management operational standards and procedures. This training was specific to water and wastewater and all member agencies were invited to attend. We have scheduled an ICS-400 (advanced incident command) course for June 30-July 1st. ICS-400 is a two-day course is designed for those emergency response personnel who would function as part of an Area Command, Emergency Operations Center, or Multiagency Coordination System during a large, complex incident or event or those personnel who are or would likely be part of a local or regional Incident Management Team during a major incident, whether single agency, multiagency or Unified Command. This course certification is also needed to ensure National Incident Management System compliance for our yearly reporting which is tied to grant funding.
Coordination with the County of Orange	Ongoing: OC OA Alert and Warning Group meetings have concluded following the release of the operational area agreement to the executive board. This was a 6-month planning effort. Daniel attended the meetings and worked with the County's Control One (Dispatch) to address some of WEROC's concerns. These concerns were associated with emergency notification obligations.

Coordination with the County of Orange (cont.)	Completed: WEROC staff participation in the OA Agreement Revision Working Group. Update: The Draft Revised Agreement developed by the working group has been reviewed and approved by the County's Legal Counsel. The OA shared this revised draft to all OC government entities and requested input by October 31st. The input was provided by WEROC and about five other agencies. The OA will develop the final agreement that will need to be approved by all agencies.
PSPS Events	On-going: California Public Utilities Commission (PUC) proceedings regarding the Impacts from De-Energization with a Focus on First Responders and Local Government. MWDOC has received party status to these proceedings. Party Status was intended to ensure that we receive all communications regarding the proceedings and that our comments are included officially for consideration. Phase 2 (permanent program) is underway. Over the past month, a number of PSPS events have been planned by SCE and SDG&E. Work is underway to improve communications. Our belief is that only two circuits were actually de-energized during the recent Red Flag events. WEROC plugged into the available information and coordinated communications with our agencies.
EOC Readiness	Janine Schunk and Daniel participated in the OA and MET radio tests and WebEOC tests. Janine also facilitated the WEROC monthly radio test. Daniel and Janine have installed all the satellite phone cradles and power stations and are currently waiting on the contractor to repair our satellite rooftop antenna. WEROC will be picking up the MWDOC emergency generator to install a solar battery maintainer system sometime in December. Janine coordinated the maintenance of the South EOC (SEOC) and is working to register the new MWDOC alt EOC generator. She has also been working on updates to Safety Center, the COOP, and position binders. WEROC has recently signed a service agreement with the City of Fountain Valley Public Works to service MWDOC's emergency generator.

Status of Water Use Efficiency Projects

November 2019

Description	Lead Agency	Status % Complete	Scheduled Completion or Renewal Date	Comments
Smart Timer Rebate Program	MWDSC	Ongoing	Ongoing	In October 2019, 240 smart timers were installed in Orange County. To date, 26,124 smart timers have been installed through this program.
Rotating Nozzles Rebate Program	MWDSC	Ongoing	Ongoing	In October 2019, 75 rotating nozzles were installed in Orange County. To date, 568,249 rotating nozzles have been installed through this program.
SoCal Water$mart Residential Indoor Rebate Program	MWDSC	Ongoing	Ongoing	In October 2019, 228 high efficiency clothes washers and 21 premium high efficiency toilets were installed in Orange County. To date, 120,038 high efficiency clothes washers and 60,461 high efficiency toilets have been installed through this program.
SoCal Water$mart Commercial Rebate Program	MWDSC	Ongoing	Ongoing	In October 2019, 133 residential premium high efficiency toilets, 326 commercial premium high efficiency toilets, and 1 ice making machine were installed in Orange County. To date, 107,048 commercial devices have been installed through this program.
Industrial Process/ Water Savings Incentive Program (WSIP)	MWDSC	Ongoing	Ongoing	This program is designed to improve water efficiency for commercial customers through upgraded equipment or services that do not qualify for standard rebates. Incentives are based on the amount of water customers save and allow for customers to implement custom water-saving projects. Total water savings to date for the entire program is 914 AFY and 4,136 AF cumulatively.

Description	Lead Agency	Status % Complete	Scheduled Completion or Renewal Date	Comments
Turf Removal Program	MWDOC	Ongoing	Ongoing	In October 2019, 20 rebates were paid, representing $46,351 in rebates paid this month in Orange County. To date, the Turf Removal Program has removed approximately 22.5 million square feet of turf.
Spray to Drip Conversion Program	MWDOC	Ongoing	Ongoing	This is a rebate program designed to encourage residential and commercial property owners to convert their existing conventional spray heads to low-volume, low-precipitation drip technology. To date, 256 residential sites and 69 commercial sites have completed spray to drip conversion projects.
Recycled Water Retrofit Program	MWDSC	Ongoing	Ongoing	This program provides incentives to commercial sites for converting dedicated irrigation meters to recycled water. To date, 157 sites, irrigating a total of 1,563 acres of landscape, have been converted. MWDOC has paid a total of $56,950.00 in grant funding to 20 of those sites. The total potable water savings achieved by these projects is 3,362 AFY and 10,907 AF cumulatively.