Department of Water Resources
Status Report on Preliminary Operations Simulations to Assess the Effects of Water Resources Challenges and Management Responses

Decisionmakers, including Governor Schwarzenegger and Department of Water Resources Executive, have asked about the effectiveness of potential management responses given current water resources challenges facing the State. DWR staff developed a work plan to apply tools that would quantify both challenges and responses. This evaluation is on-going and this paper describes analyses completed to date. In addition, recommendations are included for completing the assessment and providing comprehensive information for decisionmakers and the public. The analyses and summary provided here is preliminary.

Current Challenges

Current events point to three significant challenges:

- Delta Health
- Climate Change
- Drought

Each of these presents a difficult challenge currently and the effects of each are anticipated to worsen over time. The effects of the challenges are cumulative, meaning the effects will build upon one another. And, the challenges are not independent and experts anticipate that the effects of one challenge will increase the effects of the others. For example, absent substantial intervention, Delta health will decline more rapidly due to effects of climate change such as sea level rise and reduced runoff. Drought exacerbates conditions for at-risk species as well. Droughts will become more difficult to manage with climate change. And droughts are projected to become more frequent and more intense with a changed climate.

This paper provides a preliminary assessment of the future performance of the CVP and SWP systems. The paper describes and quantifies the effects of Delta health, climate change, and drought. The focus on current and future challenges is then followed by a discussion and quantification of potential facilities management responses. This paper focuses on the potential effectiveness of two infrastructure improvements receiving significant attention recently – new Delta conveyance and new storage. In addition, the paper will discuss and quantify some potential effects of a range of water management responses in the South Coast Region. Finally, this paper includes three recommendations related to the use of DWR's assessment tools.

Delta Health. The health of the Delta estuary has been in decline for some time. The decline is due to numerous human factors including water operations, invasive species, and urban and agricultural pollution.[i] In December 2007, Judge Oliver Wanger ruled that CVP and SWP operations needed modification to support fish recovery. The "interim remedy" was temporary and new long-term regulations have been developed. These long-term regulations are part of Biological Opinions by US Fish and Wildlife Service and National Marine Fisheries Service and are likely to impact water operations to an even greater degree. Populations of a number of species that are dependent upon the Delta are in significant decline. The Wanger ruling and the new regulations are in response to these declines. Over the past several decades, a number of planning efforts have sought to improve the ecosystem health of the Delta (among other things). Currently, the Bay Delta Conservation Plan's purpose is to provide for the conservation of at-risk species in the Delta and improve its reliability as the hub of the State's water supply system.

The future of the Delta's health is difficult to predict. Many experts believe that the health of the estuary and populations of dependent species will continue to decline without significant changes. In the long term, it would be reasonable to assume that further population declines would result in further cuts to water supplies from the Delta. The Bay Delta Conservation Plan proposes to provide a comprehensive set of conservation measures and substantially modify the hydrodynamics and water operations of the Delta.[ii] The BDCP steering committee suggests that these measures and modifications would restore a number of ecosystem functions and improve the reliability of water supplies that are dependent upon the Delta.

Climate Change. California's climate and water resources have already shown impacts from a changed climate. Over the past century, sea level along California's coast has risen about seven inches. Temperatures have risen about one degree Fahrenheit. Sierra Nevada snowpack has decreased about 10 percent (1.5 MAF).[iii] Snow runoff timing has shifted to earlier in the year. Climate has become more variable. All of these effects have modified the State's hydrology and by extension the management of its water resources.

DWR has made significant progress assessing the projected effects of climate change.[iv] DWR has evaluated the effects of twelve future climate change scenarios based upon guidance from the State's Climate Action Team. Each of the historic effects described above will worsen in the future. By mid-century, additional effects are anticipated. Sea level will rise an additional 4 to 16 inches; mean temperature will rise by another 1.5 to 5.0 degrees Fahrenheit; snowpack will decrease 25 to 40 percent (3.8 to 6 million acre-feet); generally, the climate may be wetter or drier, but relatively more extreme conditions (floods and droughts) are expected; the timing and quantity of runoff will shift to a less snow-influenced hydrology.

Drought. The current statewide drought began in 2007 and is the first in the last 20 years. Statewide droughts typically occur as a result of multiple dry years. For example, 2001 was a dry year, but not a drought year for California because 2000 provided average runoff and reservoirs were relatively full entering the 2001 water year. In California, runoff and reservoir storage, which are related, are good indicators of a statewide drought. Runoff for the current drought is 53%, 60%, and 65% of average for water years 2007, 2008, and 2009 respectively.[v] Reservoir storage at the State's major reservoirs during the same period is 78%, 57%, and 69% of average.[vi] Deliveries to water users and water contractors specifically have been substantially reduced. Prior to the current drought, there were three statewide droughts in the last 100 years: 1928 – 1934, 1976-1977, and 1987-1992. Planners for the SWP and CVP typically evaluate the performance of the system or new facilities based in part upon these "driest periods."

California's climate variability is expected to continue into the future. Until as recently as ten years ago, water managers and planners assumed that the future would be similar to the past in terms of hydrology (especially runoff). Droughts were expected to recur in the future at a similar rate and intensity as the past. Climate change science has changed these assumptions. Generally, droughts are now anticipated to be more frequent and more intense. This amplification of extremes is reflected in all twelve climate change scenarios examined by DWR.

Evaluating Delta Health, Climate Change, and Drought

The public and decisionmakers want to understand the effects of these challenges. DWR has developed comprehensive tools that can assess some of the effects of Delta health, climate change, and drought. Similarly, these tools can provide helpful information for understanding the performance of management responses. The tools do not provide a statewide assessment, but do provide detail on operations associated with the State Water Project and Central Valley Project, and water resources of the central valley and the Delta. These tools have recently been refined to more effectively assess the effects of climate change. The tools have also been refined to assess the effects of Judge Wanger's ruling. However, the effects of the proposed long-term regulations remain uncertain. Therefore, this paper reflects evaluation of the effects of the Wanger ruling rather than the newer Biological Opinions. When the effects of the new regulations become available, DWR will modify its tools and analysis to reflect the new regulatory conditions.

Generally, assumptions are based upon the CALFED, DWR, and Reclamation Common Assumptions process. Simulations use the 9B1 model with a 2030 level of development. The DWR- Reclamation Coordinated Operations Agreement is maintained and CVPIA b(2) discretionary actions are modeled.

Quantifying the Effects of Water Resources Challenges and Management Responses

The following discussion summarizes important data and conclusions related to the decisionmaker's request modeling effort. Later, we submit three recommendations related to this and future modeling study efforts:

As noted previously, we identified three water resources challenges to assess. For this challenge assessment, we analyzed the effects of:

- Delta Health using a Wanger level of regulation
- Climate Change using one representative climate change scenario from the twelve evaluated in the recently released climate change report
- Drought using "driest periods" reporting metrics. In the 83 year hydrologic record, 15 years are included in the three statewide drought periods (1928 – 1934, 1976-1977, and 1987-1992) as previously described.

In addition, we evaluated the effects of three infrastructure management responses that have been discussed over the past several years:

- New Delta conveyance using planning assumptions from the Bay Delta Conservation Plan dated January 2009. Note that BDCP assumptions are changing and likely to change further. These assumptions would need to be modified in future simulations.
- New surface storage (Sites Reservoir) using planning assumptions from the North-of-the-Delta Offstream Storage investigation. Current NODOS formulations are multi-objective and include water for restoration and water quality improvement actions. In order to provide simple comparative performance results, the formulation used here, by contrast, includes a singular water supply reliability objective, increasing deliveries to CVP and SWP contractors.
- Additional south of Delta groundwater storage using theoretical planning assumptions that reflect essentially unlimited groundwater storage capacity (5 MAF) that can receive water from and deliver water to the California Aqueduct. Previous studies have shown that storage is not a limiting factor and that put and take capacity controls operations. This analysis will give readers a sense of performance capability of a maximized south of Delta groundwater storage project. Additional facilities and agreements would be required for this type of operation.

To provide comparative results, we developed the following five futures:

Future 1: Decision 1641 regulatory environment with historical hydrology (1922-2003).

Future 2: Future 1 with Wanger-type regulation of Delta operations. South Delta exports are managed to reduce entrainment of fish and food resources. Limits for Old and Middle River flow are -3,500 cfs December through June and -5,000 cfs July through November.

Future 3: Future 2 with BDCP isolated facility and mid-level criteria. Assumptions include an isolated facility capacity of 15,000 cfs; Banks Pumping Plant capacity of 10,300 cfs; 5,000 – 11,000 cfs bypass flow requirements; modification of Fremont Weir and Yolo Bypass to provide more frequent and greater inundation; and closure of the Delta Cross Channel for water quality protection.

Future 4: Future 3 with Sites Reservoir. New storage capacity is 1.8 MAF; new diversion capacity is 2,000 – 4,000 cfs: release to the river capacity is 1,500 – 3,000 cfs.

Future 5: Future 4 with 5 MAF additional South of Delta Groundwater Bank. Maximum recharge rate from north of Delta storage is 300 cfs; unlimited recharge from excess; 2,500 cfs maximum extraction rate.

This approach allows us to quantify the incremental effects of each change. For example, Future 2 is compared against Future 1. Future 3 is compared against Future 2, etc. Climate change studies are similarly compared. Future 2 CC is compared against Future 1 and then Future 3 CC is compared against Future 2 CC, etc. In addition, we operated new storage using two approaches. First, we operated storage to mitigate North of Delta climate change effects. These simulations are designated "Local" because the water from storage is used to support local users. The second approach was to use additional storage to support SWP deliveries and is designated with "SWP". For climate changed conditions, both Future 4's are compared against Future 3. Future 5 Local is compared against Future 4 Local and Future 5 SWP is compared against Future 4 SWP. Using a slightly modified operational strategy to partially mitigate some climate change conditions, average effects upon total deliveries from CVP and SWP are:

A reduction of 803 TAF/year from Wanger

A reduction of 340 TAF/year from Climate Change

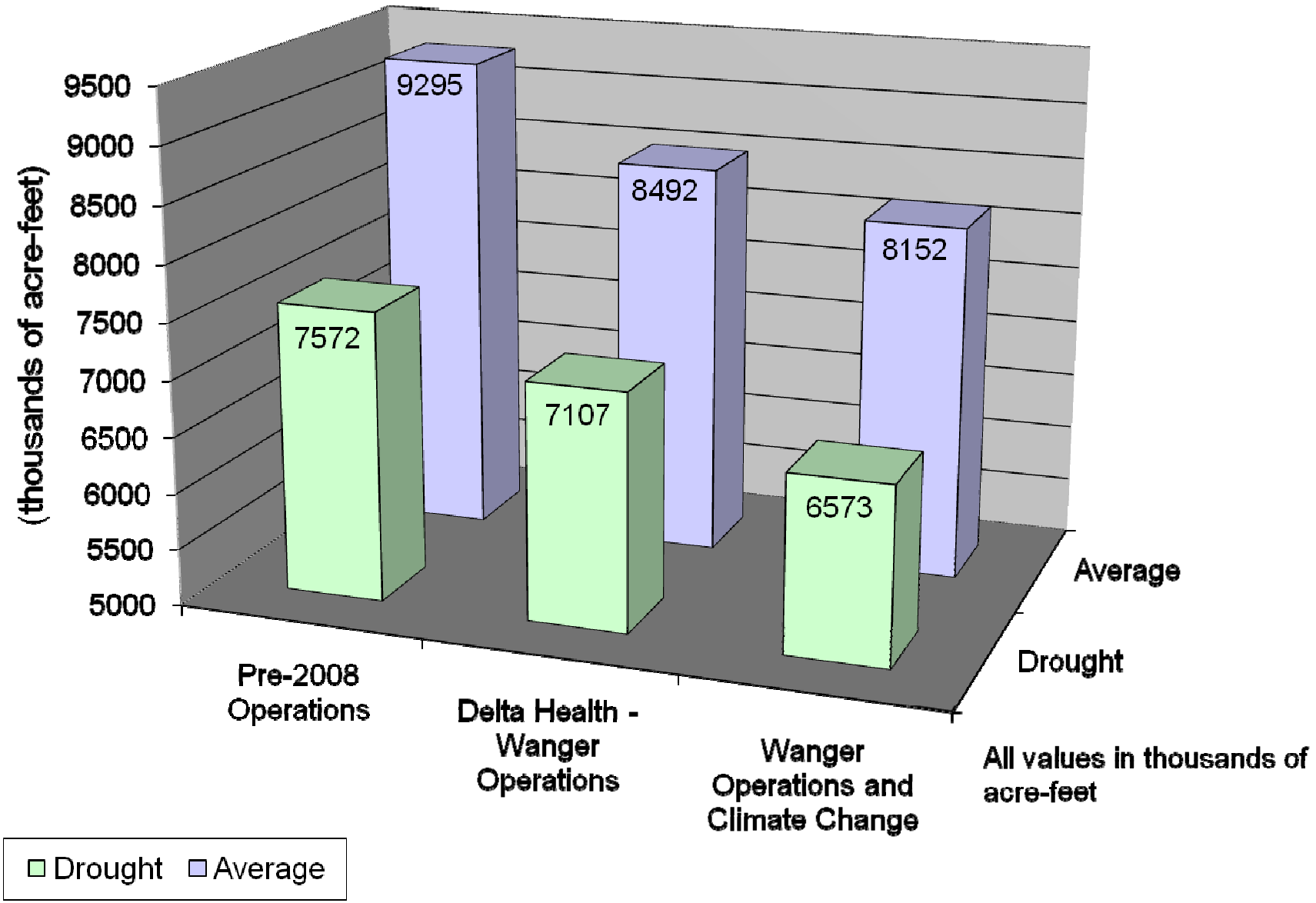
A reduction of 1,579 TAF/year from Drought

These effects accumulate so that the total reduction in average deliveries from Wanger and climate change is about 1.1 MAF. Drought reduces deliveries an additional 1.6 MAF, for a total reduction of about 2.7 MAF for all three conditions. The challenges are depicted graphically in Figure 1, which follows.

Finally, we also report the challenge effects and effectiveness of responses for "dry" and "critical" years. As noted previously, these classifications do not necessarily indicate a drought since a single year can be "critical" based upon reservoir inflow.

However, reservoir carryover storage may substantially mitigate below normal inflow. “Dry” and “critical” year effects provide an additional performance measure that occurs in 30 years of the 83 year historic hydrologic record used by CALSIM.

Figure 1. Total CVP & SWP Deliveries with Challenges



Effectiveness of New Delta Conveyance and New Storage

Additional facilities significantly restore SWP and CVP deliveries that have been diminished by the recent challenges. New conveyance, using BDCP assumptions, restores more than the water lost to Wanger (862 TAF delivery improvement with BDCP and 803 TAF delivery reduction due to Wanger). Sites Reservoir provides an additional 375 TAF. Additional groundwater storage south of the Delta provides additional improvements (about 100 TAF) to the existing system delivery capability. However, with climate change, the improvements shift. New conveyance with climate change provides about 600 TAF of additional deliveries. The addition of Sites Reservoir provides over 500 TAF and restores deliveries to pre-Wanger and pre-climate change levels. Groundwater storage provides almost 200 TAF. Both Future 4's are compared against Future 3. Future 4 Local dedicates the Sites Reservoir storage for local deliveries in an attempt to mitigate some climate change effects. Future 5 Local is compared against Future 4 Local. Table 1 shows the average effects of both challenges and management responses. As noted previously, the change in deliveries is calculated based upon a comparison with the previous future.

Table 1. Challenges and Responses: Average Effects Upon Deliveries (thousands of acre-feet)

Scenario	NOD SWP and CVP Deliveries	Delta SWP and CVP Deliveries	Total SWP and CVP Deliveries	Change in Deliveries
Future 1	3,286	6,009	9,295	
Future 2	3,270	5,222	8,492	-803
Future 3	3,278	6,076	9,354	862
Future 4	3,276	6,453	9,729	375
Future 5	3,275	6,547	9,822	93
Future 2 CC	3,240	4,912	8,152	-1,143
Future 3 CC	3,250	5,537	8,787	635
Future4 CC Local	3,228	5,538	8,766	-21
Future 4 CC SWP	3,250	6,055	9,305	518
Future5 CC Local	3,228	5,774	9,002	236
Future 5 CC SWP	3,252	6,238	9,490	185

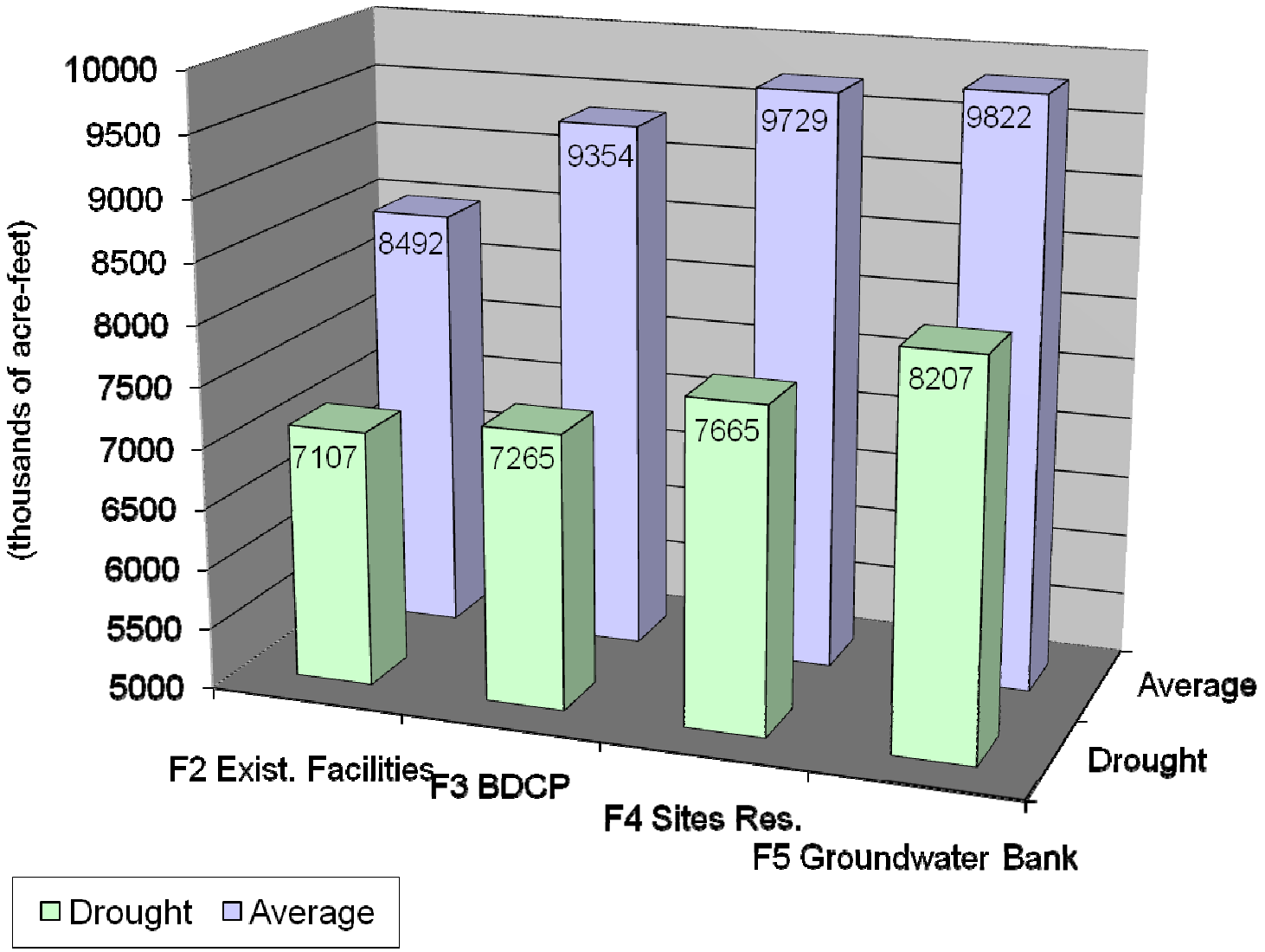
Drought deliveries indicate a similar pattern. Generally, new conveyance, Sites and groundwater storage are all required to recover the system to pre-Wanger and pre-climate changed conditions during drought. As noted previously, drought is quantitatively the greatest challenge based upon our current assessments and shown in Table 2. Drought deliveries with new conveyance increase almost 160 TAF. Sites Reservoir drought delivery improvements are 400 TAF and groundwater storage drought delivery improvements are over 500 TAF. Figure 2 illustrates the effectiveness of new conveyance and new storage. Figure 3 illustrates the effectiveness of new facilities with climate change.

Table 2. Challenges and Responses: Effects Upon Deliveries During Drought (thousands of acre-feet)

Scenario (Drought)	NOD SWP and CVP deliveries	Delta SWP and CVP Deliveries	Total Deliveries	Change in Deliveries
Future 1	2,806	4,766	7,572	
Future 2	2,806	4,301	7,107	-465
Future 3	2,790	4,475	7,265	158
Future 4	2,781	4,884	7,665	400
Future 5	2,773	5,434	8,207	542
Future 2 CC	2,638	3,935	6,573	-999
Future 3 CC	2,671	4,273	6,944	371
Future 4 CC Local	2,709	4,248	6,957	13
Future 4 CC SWP	2,659	4,542	7,201	257
Future5 CC Local	2,699	4,680	7,379	422
Future 5 CC SWP	2,656	5,105	7,761	560

New conveyance drought deliveries with climate change are improved by about 370 TAF. Sites Reservoir drought deliveries with climate change are improved by an additional 260 TAF and groundwater storage drought deliveries with climate change are improved by another 560 TAF. Table 3 shows the delivery effects of challenges and management responses during dry and critical conditions.

Figure 2. Total CVP & SWP Deliveries with New Facilities



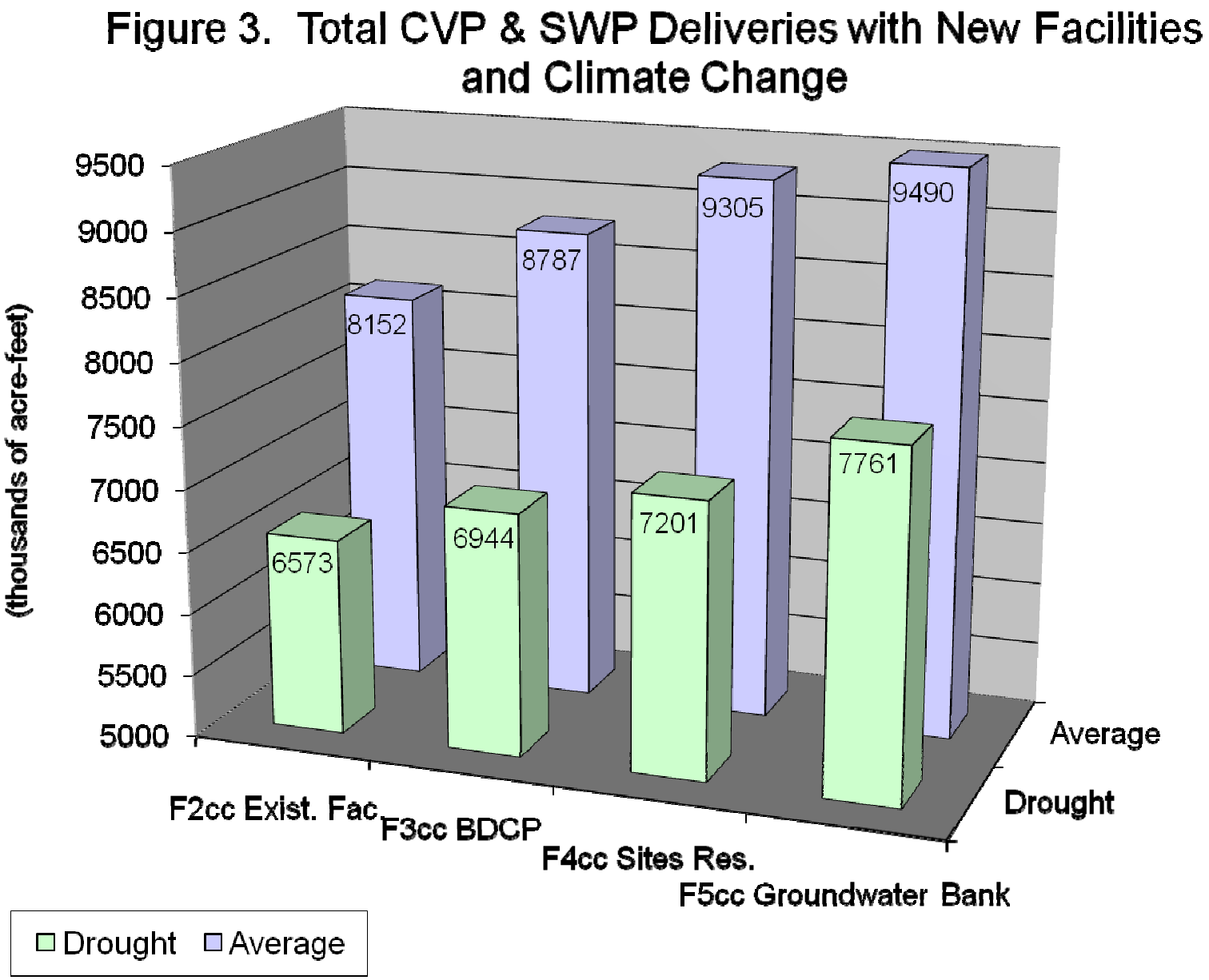


Figure 3. Total CVP & SWP Deliveries with New Facilities and Climate Change
(thousands of acre-feet)
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
8152
8787
9305
9490
6573
6944
7201
7761
F2cc Exist. Fac
F3cc BDCP
F4cc Sites Res.
F5cc Groundwater Bank
Average
Drought
Drought
Average

Table 3. Challenges and Responses: Effects Upon Deliveries, Dry and Critical Conditions (thousands of acre-feet)

Scenario (Dry and Critical)	NOD SWP and CVP Deliveries	Delta SWP and CVP Deliveries	Total SWP and CVP Deliveries	Change in Deliveries
Future 1	3,032	4,608	7,640	
Future 2	3,019	3,993	7,012	-628
Future 3	3,009	4,349	7,358	346
Future 4	3,012	4,881	7,893	535
Future 5	3,009	5,139	8,148	255
Future 2 CC	2,928	3,541	6,469	-1,171
Future 3 CC	2,931	3,899	6,829	360
Future4 CC Local	2,943	3,864	6,806	-23
Future 4 CC SWP	2,930	4,437	7,367	538
Future5 CC Local	2,944	4,273	7,217	410
Future 5 CC SWP	2,932	4,824	7,756	388

The following observations are made regarding the performance of potential new facilities using the operational strategy previously described:

- New conveyance and new storage provide reliability benefits under most future scenarios.
- New storage performance is significantly reduced when these new facilities are used to restore water supply reliability to north of Delta ("Local") users during climate-changed conditions. More specifically, total deliveries are slightly reduced with new storage at Sites Reservoir dedicated to local uses. Deliveries do increase when groundwater storage is added and dedicated to upstream local users.
- New conveyance performs best under average non-climate changed conditions. When climate change is introduced, additional deliveries are reduced about 25%. Under drought conditions, additional deliveries are

reduced by over 80%. With drought and climate change, deliveries are reduced by 57%.

- By contrast, new storage provides the greatest supply reliability benefit under drought and climate-changed conditions. Sites Reservoir increases deliveries by almost 40% with climate change and almost 7% with drought as compared to average. Deliveries associated with Sites Reservoir with both climate change and drought are decreased by 30%.
- New groundwater storage performs similarly, with even greater drought year performance. 5 MAF of South of the Delta groundwater storage provides less than 100 TAF improvement under average and non-climate changed conditions. Under climate-changed conditions, additional deliveries associated with groundwater storage almost double. During drought conditions, additional deliveries from groundwater storage increase by almost 6 times. During drought and climate-changed conditions, groundwater storage deliveries increase by six times that of the average non-climate changed condition.
- Half of the challenge and response effects associated with different futures during dry and critical conditions fall between the average and drought effects. For example, the delivery improvement effect for new Delta conveyance associated with BDCP and Future 3 is 862 TAF for average, 158 TAF for drought, and 346 TAF for dry and critical conditions. Dry and critical is between average and drought. The exceptions to this pattern are Future 2 CC (Delta health challenge with climate change), which shows a slightly greater than average reduction in deliveries during dry and critical conditions; Future 3 CC which provides a slightly lesser improvement in deliveries during dry and critical than drought conditions; and all Future 4 (Sites Reservoir) management responses. For example, Sites Reservoir performs best during dry and critical conditions when operated for SWP benefits (average = 375 TAF, drought = 400 TAF, and dry & critical = 535 TAF). Relatively, Sites Reservoir operated to support local deliveries associated with climate change effects performs slightly better during dry and critical conditions (average = -21 TAF, drought = 13 TAF, and dry & critical = 23 TAF).

In addition to effects upon deliveries, the simulations also determined effects upon water quality and ecosystem metrics. Tables 4 and 5 show the average X2 position by month (February through June) for the various futures.

Table 4. Challenges and Responses: X2 Position, Average Conditions (thousands of acre-feet)

Scenario	Feb	Mar	Apr	May	Jun
Future 1	63	61	66	70	76
Future 2	61	60	64	68	75
Future 3	63	62	66	71	76
Future 4	63	63	66	71	76
Future 5	63	63	67	71	75
Future 2 CC	60	61	67	72	78
Future 3 CC	63	63	68	73	79
Future 4 CC Local	63	63	68	73	79
Future 4 CC SWP	63	64	68	73	79
Future 5 CC Local	63	64	68	74	79
Future 5 CC SWP	64	64	69	73	79

Generally, X2 moves downstream and toward the Bay with Wanger operations as compared to Future 1 (pre-Wanger operations). As new facilities are added, some additional X2 movement upstream occurs. For example, X2 moves upstream by 2 kilometers in February, March, and April, and by 3 kilometers in May and 1 kilometer in June with BDCP operations. Some additional 1 kilometer movements occur as a result of additional storage operations associated with Future 4 and Future 5 as well. More significant movements upstream occur as a result of climate change (comparing Future 2 against Future 2 CC for example). These results are affected by sea level rise. April, May, and June X2 moves upstream by 3, 4, and 3 kilometers respectively with climate change. Adding BDCP facilities and operations has greatest effects upon X2 in February and March with 3 and 2 kilometers movement upstream respectively.

The location of X2 moves significantly upstream as a result of drought conditions. The relative movement as a result of Wanger operations and then additional facilities is similar and shown in Table 5. The desirable location of X2 in the future for water quality, ecosystem processes, and water supply is being discussed as part of the BDCP planning process. Figure 4 shows the average X2 location with both the water

resources challenges and potential management responses, with and without climate change.

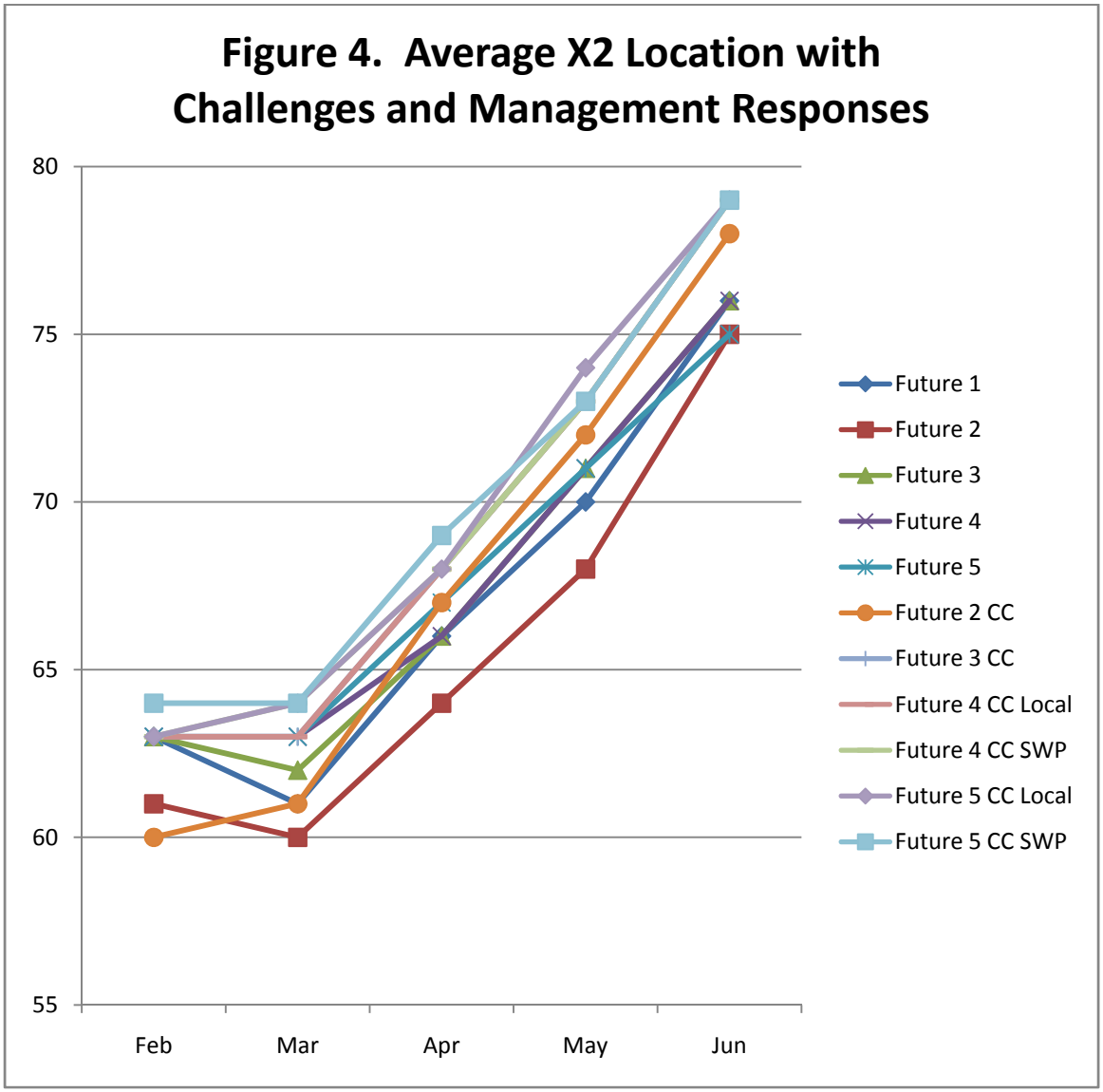


Table 5. Challenges and Responses: X2 Position, Driest Periods Conditions (thousands of acre-feet)

Scenario	Feb	Mar	Apr	May	Jun
Future 1	77	73	76	81	85
Future 2	75	71	75	80	84
Future 3	77	74	76	81	84
Future 4	77	74	77	81	83
Future 5	77	74	77	81	83
Future 2 CC	76	73	77	83	87
Future 3 CC	79	77	79	84	87
Future 4 CC Local	79	77	79	84	87
Future 4 CC SWP	79	77	79	83	87
Future 5 CC Local	79	77	79	84	87
Future 5 CC SWP	79	77	79	84	87

The Challenge of the Climate Change Challenge

Climate change is a significant challenge for managing California's water resources. Climate change (especially during drought years) has also emerged as the greatest challenge for modelers. Existing operations rules cause "system vulnerabilities" to the CVP, SWP, and central valley water resources systems. A climate change re-operation of the SWP and CVP systems appears necessary to achieve sustainable and acceptable solutions under climate-changed conditions.

More specifically, system reservoirs (Trinity, Shasta, Oroville, and Folsom) run dry (dead storage) when using existing SWP and CVP delivery logic, flow and water quality requirements, and other system requirements. Dead storage conditions should be understood as:

- No water for instream flow below the dam
- No water for local users
- No water for Delta requirements
- No water available to release for exports

Of these effects, instream flow required immediately below the dam is the one use that cannot practically get water from any other source. Local users may have some ability to get water from other sources such as groundwater. Delta requirements and exports have the most flexibility in getting water from other sources. For example, Delta requirements and exports can continue in some cases when an individual reservoir is empty if another reservoir can support the Delta needs. To illustrate the dead storage effects, a new metric, unmet instream flow, has been suggested for any additional rounds of studies.

Climate change scenario A2 GFDLCM21 at mid-century was chosen as a representative scenario and is characterized by hotter and slightly wetter conditions and the following system responses using Future 2:

- Reservoir inflows are increased by 1.4 % (198 TAF)
- Delta outflow is increased by 6.1 % (944 TAF)
- Total dead storage occurrences at four major reservoirs increases by 1,029 % (from 7 to 79 occurrences)

In addition, a one foot sea level rise is assumed for climate change simulations. Selection of a representative scenario does affect results and discussions regarding the appropriate representation of scenarios and modeling are on-going within the BDCP planning process.

We recommend that all twelve climate change scenarios be evaluated for at least one future to demonstrate the sensitivity of the system to hydrologic changes associated with climate. This proposed analysis will generate a range of potential effects associated with climate change. We anticipate that the range will provide even more compelling information related to the need to mitigate climate change effects than a singular scenario.

Note: this recommended analysis has been completed and is discussed at the end of this document.

The increase in Delta outflow is primarily due to less effective runoff capture (associated with diminished snowpack and an associated shifted timing of runoff) and increased outflow requirements (associated with sea-level rise) to meet water quality standards. The increase in Delta outflow is directly related to dead storage conditions. Less effective runoff capture and increased required outflow both empty reservoirs more rapidly. Dead storage conditions do occur to a limited degree without climate change as shown in Table 6. For Future 1 and Future 2 conditions, dead storage occurs during 0.37% and 0.17% of possible reservoir months respectively.

Table 6. Dead Storage Occurrence (Number of Reservoir Months)

Scenario	Trinity	Shasta	Oroville	Folsom	Total
Future 1	3	6	0	6	15
Future 2	1	3	0	3	7

Dead storage increases dramatically with climate change as shown in Table 7. For Future 2 with climate change, dead storage occurrences increase to 79 (2.0% of possible reservoir months), as previously noted. In addition, dead storage occurs more frequently as additional facilities are added to the system for both historical hydrology and climate changed hydrology. In each case, Future 5 (new Delta conveyance + Sites Reservoir + new groundwater storage), with Sites operated to provide SWP benefits, leads to the worst future dead storage conditions of those evaluated. CC in a scenario name designates a climate change future condition.

Table 7. Climate Change Dead Storage Occurrence (Number of Reservoir Months)

Scenario	Trinity	Shasta	Oroville	Folsom	Total
Future 2 CC	9	24	21	25	79
Future 3 CC	12	21	10	39	82
Future 4 CC SWP	15	24	17	42	98
Future 5 CC SWP	17	27	23	46	113

Folsom is especially impacted as new facilities are added. Other reservoirs are either improved or have a marginal increase in dead storage occurrence as facilities are added.

In sensitivity analyses, we found that reducing SWP and CVP deliveries cannot fully mitigate these effects at and below the major reservoirs (see Table 8). In sensitivity simulations, the only scenario where these dead storage conditions are substantially mitigated is when exports from the Delta are reduced to zero (EXP = 0). Two other sensitivity simulations were tested. In EXP LMT, combined export allocations are

limited to 3 MAF in dry years and 2 MAF in critical years. In EXP REL = 0, releases for exports from upstream reservoirs were completely eliminated and exports only occur incidentally. However, in this scenario, additional water is required to maintain Delta water quality. These sensitivity simulations indicate different results since Future 3 CC here does not modify deliveries at all; whereas in the results shown above, some modification to export deliveries were included.

Table 8. Sensitivity Test Adjusted Export Operations
Dead Storage Occurrence (Number of Reservoir Months)

Scenario	Trinity	Shasta	Oroville	Folsom	Total
Future 3 CC	19	36	17	63	135
Future 3 CC EXP = 0	0	0	0	3	3
Future 3 CC EXP LMT	10	24	4	32	70
Future 3 CC EXP REL=0	6	14	0	17	37

Modified export delivery rules have been developed for climate change futures 3, 4, and 5 so that drier year deliveries are reduced and storage is improved somewhat. These results with modified export rules are shown in Table 7 previously. In-basin user impacts such as reduced deliveries and increased groundwater pumping, as well as reduced instream flows cannot be fully mitigated by modifying CVP and SWP operations. The occurrence of dead storage in all of the climate change scenarios appear to be both unsustainable and indefensible. Modification of both CVP and SWP export delivery logic (which is included in a limited manner in this round of studies) and north of Delta delivery logic (which is not included in this round of studies) will be required.

We recommend that DWR develop a reoperation strategy for the CVP and SWP that includes modified operations scenarios to mitigate the effects of dead storage during climate change conditions prior to release of any studies (either these or BDCP) that include climate change. This approach will require modified Delta deliveries (CVP and SWP exports) and modified North of Delta contractor deliveries (e.g. Settlement Contractors) as well. This modeling can be developed based upon

dead storage occurrence targets. Development of modified operating rules are consistent with findings and recommendations from the "Managing an Uncertain Future" DWR climate change report. First, climate change, including modified hydrology caused by reduced snowpack, is already occurring. Second, the existing water resources systems, including operating rules, have been developed based upon historic hydrology. That hydrology can no longer be relied upon. By extension, the operating rules that were developed based upon historic hydrology cannot be expected to be effective either. The results described above clearly demonstrate this point.

In the simulations described previously, meeting local basin needs (instream flow requirements, CVP settlement contract entitlements, and SWP Feather River contractors) cannot be fully restored. Additional futures have been developed, designated as Local formulations of Sites Reservoir and South of Delta groundwater storage. While these futures do not provide as significant water supply benefit, they do partially mitigate North of Delta climate change effects, such as dead storage.

Economics and Integrated Water Management Measures

The economic models, like the operations model (CALSIM II), need to be re-calibrated to more accurately assess economic effects, especially with climate change. Economic assumptions that work in scenarios without climate change are not able to fully describe the economics with climate change. This deficiency is due to the large quantities of water that are no longer available under climate changed and new regulatory conditions. In addition, yield from local projects need to be modified to reflect climate change effects as well. While extending the economics will require a significant work effort, we plan to proceed with this work since the projects will want to use the economic models to describe climate change anyway.

We recommend that economic modeling and results be completed and included with prepared information. In order to develop the economic models, new multi-step operations simulations (CALSIM II) will need to be completed. New simulations can be based significantly upon decisionmaker's request work-to-date.

LCPSIM is an annual time-step urban water service system reliability management model. The model objective is to determine the economically efficient management strategy using the least-cost planning criterion. The model uses a shortage loss function derived from contingent valuation studies and water agency shortage allocation strategies. LCPSIM accounts for the ability of shortage management (contingency) measures, including water transfers, to reduce regional costs and losses associated with shortage events, and for the ability of long-term regional demand reduction and supply augmentation measures, in conjunction with regional carryover storage opportunities, to reduce the frequency, magnitude, and duration of those shortage events.

Measures are adopted in order of their cost, with lowest cost measures adopted first. Using this "selection" procedure, LCPSIM finds the point which minimizes the sum

of the total annual cost of the adopted long-term measures and the total expected annual shortage costs and losses remaining. The value of the availability of a supply from a proposed facility can be determined from the change it produces in this economically efficient point of operation.

LCPSIM output includes the economically efficient level of adoption and cost of regional reliability enhancement measures by type. Output by year is available for shortage size, costs and losses due to shortage, quantities and costs of water transfers, surface and groundwater carryover storage operations, and overall system operations costs.

LCPSIM has been used to describe the effects of integrated regional water management measures and variable demand associated with uncertain futures (consistent with Water Plan Update scenarios) upon water supply reliability and Delta operations. Descriptions of the future scenarios evaluated in the Water Plan can be found in the Public Review Draft of the 2009 update. LCPSIM, in essence, performs a water balance of South Coast supplies and demands. Unlike a traditional balance, LCPSIM determines a balance which includes an efficient level of unmet demand in light of the cost of further adoption of regional demand reduction and/or water supply augmentation measures as compared to the expected reduction in shortage costs and losses. After an initial water budget or portfolio is developed for the South Coast, LCPSIM selects and adds management measures to meet local demands until the marginal cost is greater than the marginal benefit. For the scenarios we examined, measures such as recycling are included in the 2030 baseline and are added to the portfolio based upon economic choices. For this “uncertain future” analysis, we are using our Wanger operations (Future 2) with no climate change. Deliveries from the CALSIM II simulation are used to create a time series of State Water Project supply to the South Coast.

The uncertain future assumed affects local reliability and the need for additional investments. Since investments, or local management responses, are dictated by economic decisions, the Expansive Growth future will stimulate significantly greater investment in desalting, for example. The effect of specific measures is more difficult to see in the CWPU uncertain futures since there are so many variables, including population, density, and per capita use. Some of the results are somewhat counter-intuitive because of investments that occur based upon the initial water balance. For example, Urban WUE is greater in the Current Trends future than the Strategic Growth future. This is because Strategic Growth requires a smaller investment in strategies than Current Trends. Final water balances after investments are shown in Table 9. Many of the quantities in this table include both a baseline quantity that is assumed to be available in 2030 and an investment quantity. For example, 169 TAF of Desalting in Current Trends includes 44 TAF in the baseline and 125 TAF of investment in Desalting.

Table 9. Future 2 South Coast Average Water Balance (TAF) with Water Plan "Uncertain Futures" and Economic Investments

	Current Trends	Strategic Growth	Expansive Growth
Demand	5,400	4,917	6,285
SWP	1,405	1,371	1,404
Colorado River	816	816	816
Misc. Local Supply	1,696	1,696	1,696
Desalting	187	44	948
Recycling	853	641	853
Reuse	240	245	280
Transfers	115	62	138
Change in Storage	6	-1	7
Total Supplies	5,319	4,875	6,144
Unmet Demand	84	43	147
Urban WUE (included in Demand above)	825	777	519
Reliability (Unmet Demand / Demand	1.5 %	0.9%	2.3%
Option Marginal Cost (per AF)	$1,809	$1,025	$2,060
Total Options Cost (million $ / year)	$833	$209	$2,387

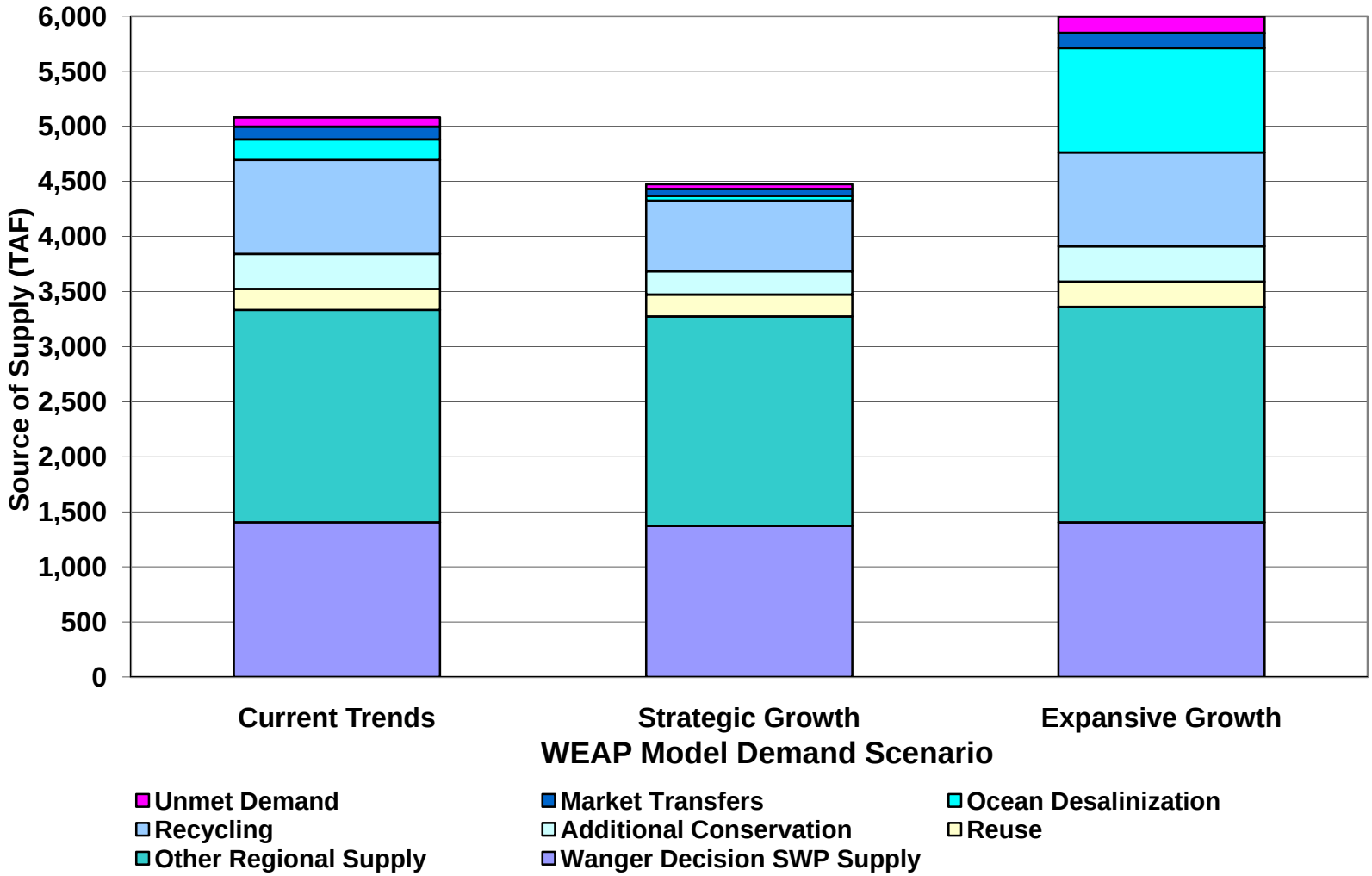
However, as demand varies in the South Coast Region, which is captured by the three futures, there is limited discernable long-term effect upon Delta operations (deliveries or outflow). Table 10 depicts the delivery reductions associated with the uncertain future scenarios in the South Coast. Figure 5 shows the effects of tables 9 and 10 graphically.

Table 10. Future 2 Reductions in SWP Deliveries to South Coast (TAF), 1922 – 2004

	1983	1986	1998	All other years	Average
Current Trends	585	0	14	0	7
Strategic Growth	681	285	497	0	18
Expansive Growth	276	0	60	0	4

There are no changes in deliveries to the South Coast in 79 of 82 years. This analysis affirms that modifications to use (within the range evaluated here) in the contractor service areas have little effect upon operations in the Delta. However, as stated previously, modifying use can provide significant reliability improvements and investment needs in the service areas themselves.

Figure 5. South Coast Region Water Management Example



Recommended Climate Change Analysis

As recommended above, we subsequently evaluated the effects of all twelve climate change scenarios for Future 5, which includes Wanger-type regulation of the Delta, January 2009 BDCP planning assumptions with an isolated facility and mid-level criteria, Sites Reservoir, and additional groundwater storage south of the Delta. This future reflects an aggressive implementation of new facilities to improve and integrate statewide systems, including 7 MAF of additional storage and new delta conveyance, and supporting water supply reliability and ecosystem restoration improvements. In addition, LCPSIM has been applied to the Future 5 results. The range of effects associated with the twelve climate change scenarios and Future 5 is shown in Table 11. The Future 5 base is labeled Future5 SWP (no CC) and the twelve climate change scenarios are labeled F5SWP and then the designated climate change scenario such as, "A2 CNRMCM3."

Table 11. Challenges and Responses: Average Effects Upon Deliveries with Climate Change and Future 5 SWP (thousands of acre-feet)

Scenario	NOD SWP and CVP Deliveries	Delta SWP and CVP Deliveries	Total SWP and CVP Deliveries	Change in Deliveries
Future5 SWP (no CC)	3,275	6,547	9,822	
F5 SWP A2 CNRMCM3	3,177	5,698	8,875	-947
F5 SWP A2 GFDLCM21	3,319	6,300	9,619	-203
F5 SWP A2 MIROC32MED	3,045	5,458	8,503	-1,319
F5 SWP A2 MPIECHAM5	3,285	6,149	9,434	-388
F5 SWP A2 NCARCCSM3	3,166	5,862	9,028	-794
F5 SWP A2 NCARPCM1	3,178	5,884	9,062	-759
F5 SWP B1 CNRMCM3	3,320	6,257	9,577	-245
F5 SWP B1 GFDLCM21	3,347	6,439	9,786	-36
F5 SWP B1 MIROC32MED	3,008	5,365	8,373	-1,449
F5 SWP B1 MPIECHAM5	3,315	6,227	9,542	-279
F5 SWP B1 NCARCCSM3	3,163	5,884	9,047	-775
F5 SWP B1 NCARPCM1	3,363	6,546	9,909	86

The effects upon deliveries range from an increase of 1% to a decrease of 15%. Only one scenario generates an increase in deliveries as compared to the non-climate changed scenario.

The effects upon the previously discussed dead storage condition are shown in Table 12.

Table 12. Climate Change Dead Storage Occurrence (Number of Reservoir Months) With Climate Change and Future 5 SWP

Scenario	Trinity	Shasta	Oroville	Folsom	Total
Future5 SWP (no CC)	4	8	15	11	38
F5 SWP A2 CNRMCM3	43	46	42	78	209
F5 SWP A2 GFDLCM21	0	0	1	4	5
F5 SWP A2 MIROC32MED	64	84	62	142	352
F5 SWP A2 MPIECHAM5	5	13	21	32	71
F5 SWP A2 NCARCCSM3	40	46	53	81	220
F5 SWP A2 NCARPCM1	37	50	35	75	197
F5 SWP B1 CNRMCM3	4	11	10	16	41
F5 SWP B1 GFDLCM21	0	1	16	6	23
F5 SWP B1 MIROC32MED	70	84	55	156	365
F5 SWP B1 MPIECHAM5	8	13	11	24	56
F5 SWP B1 NCARCCSM3	40	49	35	69	193
F5 SWP B1 NCARPCM1	6	11	4	21	42

The range of effect is again significant. The A2 GFDLCM21 climate change scenario shows a relative improvement in dead storage by reducing occurrences to only 5, while the B1 MIROC32MED scenario shows an increase to 365 occurrences. The number of occurrences of dead storage has decreased in two scenarios and increased in ten.

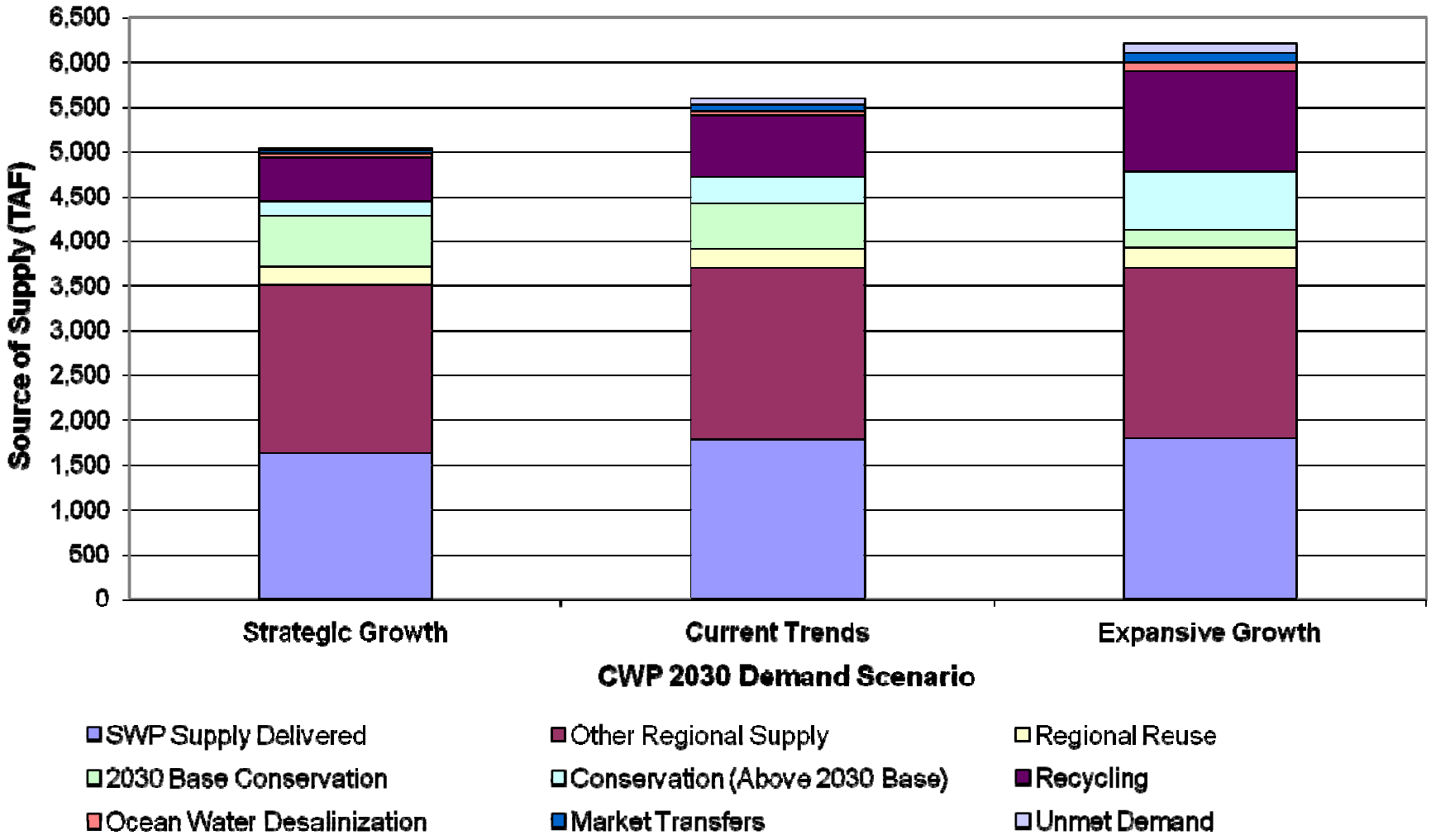
The example effects of these climate change conditions on water management in southern California are shown in Table 13 and Figure 6. The three plausible future conditions scenarios from the water plan are shown here. Climate scenario is A2 NCARPCM1 and Future 5 assumptions are used.

Table 13. South Coast Average Water Balance (TAF) with Water Plan "Uncertain Futures" and LCPSIM Economic Investments Future 5 SWP with Climate Scenario A2 NCARPCM1

	Current Trends	Strategic Growth	Expansive Growth
Demand	5,420	4,973	5,959
SWP	1,785	1,626	1,797
Colorado River	816	816	816
Misc. Local Supply	1,696	1,696	1,696
Desalting	44	44	86
Recycling	694	504	1,132
Reuse	253	249	270
Transfers	74	37	114
Change in Storage	4	-20	-40
Total Supplies	5,446	4,953	5,858
Unmet Demand	60	20	95
Urban WUE (included in Demand above)	805	721	846
Reliability (Unmet Demand / Demand)	1.1 %	0.4%	1.6%
Option Marginal Cost (per AF)	$1,290	$547	$1,624
Total Options Cost (million $ / year)	$328	$75	$1,112

Economic investments are significantly modified by which future is assumed. In Future 5, substantial investments have already been made in storage and conveyance. In addition, the Strategic Growth future has already invested heavily in conservation. All of these factors affect optional marginal costs and total option costs. Figure 6 shows more clearly the total effect of the water plan plausible futures on the water balance for South Coast Region.

Figure 6. South Coast Region Water Management Example Climate Scenario A2 NCARPCM1



Assuming Future 5 and Strategic Growth results in more significant reductions in State Water Project deliveries than previously shown in the Future 2 example. Future 5 includes both surface and groundwater storage and new Delta conveyance. The biggest difference in terms of effect upon water demand in the plausible futures is population. The South Coast Region population in 2030 is 22.5 million, 24.3 million, and 27.0 million for Strategic Growth, Current Trends, and Expansive Growth respectively. Current Trends has an 8 percent greater population than Strategic Growth and Expansive Growth has an 11 percent greater population than Current Trends. In the 83 year record, average undelivered SWP supply is 13 TAF, 172 TAF, and 1 TAF for Current Trends, Strategic Growth, and Expansive Growth respectively. 172 TAF represents about 10% of the average SWP supply for Southern California.

Finally, we also determined how these scenarios appear to address the 20% by 2020 initiative. Estimates were requested by members of the Statewide Water Analysis Network, a technical advisory group associated with the California Water Plan. Assumptions related to conservation and recycling measures and program credit were derived from the recent water legislation. For the 20% by 2020 program, the South Coast Region has a target 2020 effective per capita water use of 149 gallons per capita day (gpcd). Based upon results from the above scenarios, the 2030 effective per capita use is 144 gpcd, 144 gpcd, and 134 gpcd for Strategic Growth, Current Trends, and Expansive Growth respectively. This result is somewhat counterintuitive, but is likely related to the very large investments in recycling made under the Expansive Growth scenario.

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[i] California Department of Water Resources, Pre-final Draft California Water Plan Update 2009, page 4-16, October 2009
[ii] California Natural Resources Agency, Bay Delta Conservation Plan, A Collaborative Approach to Restore the Delta Ecosystem and Protect Water Supplies, An Overview and Update, page 6, March 2009
[iii] DWR, Draft Water Plan
[iv] DWR, Managing an Uncertain Future, Climate Change Adaptation Strategies for California's Water, October 2008
[v] DWR, "California's Drought Update, October 30, 2009," page 5, October 2009
[vi] DWR, "California's Drought Update, October 30, 2009, page 4, October 2009