




















DWR Contributes to California's Fourth Climate Change Assessment

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DWR Climate Change Program

	1987 <ul style="list-style-type: none"> DWR Hydrologist Maury Roos addresses snowmelt runoff changes at Pacific Climate Workshop
	1988 <ul style="list-style-type: none"> DWR Deputy Director Robert Potter testifies at legislative hearing about climate change (CC) affecting California (CA) water resources
	1991 <ul style="list-style-type: none"> DWR releases study on decline in snowpack runoff since the early 1900s
	1993 <ul style="list-style-type: none"> The Water Plan identifies climate change as a potential threat to CA's water resources
	1997 <ul style="list-style-type: none"> Twitchell Island Wetland Research Facility opens, gauging subsidence in the Delta
	2006 <ul style="list-style-type: none"> DWR releases major report about CC's effect on water resources as part of CA's 1st Climate Change Assessment
	2007 <ul style="list-style-type: none"> DWR's first submittal of greenhouse gas (GHG) emissions to CA Climate Registry DWR awarded Climate Action Leader award DWR wins communication award for "Science on a Sphere" at State Fair DWR re-establishes State Climatologist Office
	2008 <ul style="list-style-type: none"> DWR releases climate adaptation strategy for water - <i>Managing an Uncertain Future</i> DWR forms 1st CC Technical Advisory Group (CCTAG) DWR staff invited to deliver lecture to the Executive Council of the World Meteorological Organization of the United Nations in Geneva, Switzerland.
	2009 <ul style="list-style-type: none"> California Water Plan (CWP) includes CC in projections of future demand DWR Sustainability Policy adopted DWR CEQA CC Committee (C4) forms DWR produces mini-documentary "A Climate of Change" DWR Climate Change Program becomes official DWR releases scientific research contributing to California's 2nd Climate Change Assessment
	2010 <ul style="list-style-type: none"> C4 releases staff guidance on CEQA CC & GHG emissions analysis Prop 84/Prop 1E Grant Guidelines add CC Standard DWR adopts environmental stewardship policy & sustainability targets
	2011 <ul style="list-style-type: none"> DWR launches Climate News Digest DWR debuts the <i>Climate Change Handbook for Regional Water Planning</i>
	2012 <ul style="list-style-type: none"> DWR introduces Climate Action Plan: Phase 1 (GHG Reduction Plan) DWR contracts w/Lodi Energy Center for high efficiency power DWR receives Sustainable Business of the Year award DWR forms 2nd CCTAG California's Third Climate Change Assessment released - DWR serves on Steering Committee
	2013 <ul style="list-style-type: none"> DWR does not renew power contract with Reid-Gardner Power Plant, a major source of the Department's CO₂ emissions
	2014 <ul style="list-style-type: none"> CWP Update 2013 analyzes future climate change demand & supplies, plus the link between adaptation, mitigation, & water-energy (CWP Update 2013) DWR releases 2015 Drought Tree Ring Study
	2015 <ul style="list-style-type: none"> DWR receives 1st national Climate Leadership Award
	2016 <ul style="list-style-type: none"> DWR engages in CC Tribal Coordination and Traditional Environmental Knowledge Initiatives DWR receives 2nd national Climate Leadership Award Climate Action Plan earns award from the American Society of Civil Engineers
	2017 <ul style="list-style-type: none"> DWR receives State of the Estuary award for carbon sequestration projects
	2018 <ul style="list-style-type: none"> Climate Action Plan: Phase 2 (climate change analysis guidance) adopted DWR receives 3rd national Climate Leadership Award DWR releases scientific research contributing to California's 4th Climate Change Assessment
	2019 <ul style="list-style-type: none"> DWR earns "Climate Registered" status for the 8th consecutive year

The State of California recognizes that climate change fundamentally will challenge the complex water system on which Californians rely. Science is a key ingredient to understand and prepare for changes in climate. DWR is committed to using the best available science to inform management decisions, and is a proven leader in the development, support for, and use of climate science. On continuing its climate change leadership, it provided original, actionable science to California's Fourth Climate Change Assessment (CCA4), released in August 2018.

- Ted Sommer, DWR Lead Scientist

Building on a long history of contributing knowledge, data, and awareness about the risks of climate change to California's vital water resources (see timeline sidebar), DWR staff scientists and engineers contributed to nine technical reports and supporting scientific articles for California's Fourth Climate Change Assessment. This original research ranges from model-based assessments and projections to social science studies documenting local resource management perspectives and efforts. Also part of the Assessment, DWR contributed to the Climate Safe Infrastructure Panel (AB 2800) report, "Paying It Forward," which provides state agencies with guidance on how to account for climate change impacts in all aspects of managing of state infrastructure.

The DWR original research papers are a major contribution to the full climate change assessment which addressed climate change impacts, vulnerabilities, and adaptations in a series of 51 technical reports, nine regional reports, three special topics reports, and a statewide summary. This body of work demonstrates one of many ways that DWR is continuing to increase the knowledge and awareness of climate change impacts, which can inform adaptation of water management in California. Below presents synopses of the reports and the implications of each for DWR and water resources management more broadly in California. **Full reports available for download at www.climateassessment.ca.gov/.**

Summaries of DWR Contributions

The nine studies contributed by DWR staff as part of or supporting the State's Fourth Climate Change Assessment can help to answer a variety of questions related to climate change impacts and adaptation in California. These studies use different expertise from hydrology and downscaling projections to translating how projected climate impacts differ in each of the state's hydrologic regions to conducting social science to understand needs and experiences of local water managers. Including this work as part of the state's assessment will increase its accessibility and use beyond the scientific publications. The summaries below are organized into modelled projections and impacts and then studies on local planning for climate change. The report concludes with remarks on the implications of the studies' findings for DWR.

He, M., A. Schwarz, E. Lynn, M. Anderson. 2018. Projected Changes in Precipitation, Temperature, and Drought across California's Hydrologic Regions. California's Fourth Climate Change Assessment. Publication number: CCCA4-EXT-2018-002.

He et al. (2018) investigated potential changes in future precipitation, temperature, and drought across 10 hydrologic regions in California. Changes were explored in terms of differences from a historical baseline and the changing rate (trend slope). Results indicated that warming is expected across all regions in all temperature projections, increasingly in late century (Figure 2). However, no such consensus was found in precipitation, for which projections ranged from -25 percent to +50 percent compared to the historical baseline (Figure 1). On average, projected precipitation changes are small compared to the natural variability observed in historical precipitation. Compared to wet regions, dry regions are projected to have higher increases in temperature and more severe droughts. The study also shows that the coolest North Lahontan region tends to have the highest increases in both minimum and maximum temperature. The region is also projected to experience increases in wet season precipitation which are likely attributed to expected warming in this region. For the driest region, the Colorado River region, all projections consistently show rising trends in temperature and drought risk compared to their historical counterparts.

Maendly, R. 2018. Development of Stage-Frequency Curves in the Sacramento – San Joaquin Delta for Climate Change and Sea Level Rise. California's Fourth Climate Change Assessment. Publication number: CCCA4-EXT-2018-011.

This study presented a method to create stage-frequency curves for three scenarios: 1) current hydrology, 2) current hydrology with sea level rise, and 3) climate change hydrology with sea level rise in the Sacramento-San Joaquin Delta (Delta). The study used two hydraulic models in concert, the Central Valley Floodplain Evaluation and Delineation hydraulic models, and RMA Bay-Delta model. Three sets of data, the Central Valley Hydrology Study, eastside river inflows, and tides and storm surge at the Golden Gate Bridge were used as input for those models. Once the method was applied and validated, 126 stage-frequency curves were developed and analyzed for those three scenarios for 54 index point locations in the Delta. This method was used to inform the Central Valley Flood Protection Plan 2017 Update.

Results from the study showed that sea level rise has a larger effect on water surface elevation in locations closer to the center of the Delta. This effect is due to the decrease in the channel bottom's slope of the Delta and the amplitude of the tide. For larger flood events, the effect of sea level rise diminishes because flood-flow drives the water surface elevation. Climate change hydrology shifts the stage-frequency curve to more frequent, larger flood events and has a greater impact on water surface elevation in the San Joaquin River with stage increase of as much as seven feet for the 200-year return period flood event. This type of event could jeopardize the flood protection level of the City of Stockton and neighboring communities.

Figure 1. Percent Differences (%) between Historical and Mean Projections on (a) Annual Precipitation in Mid-Century, (b) Wet Season Precipitation in Mid-Century, (c) Annual Precipitation in Late Century, and (d) Wet Season Precipitation in Late Century.

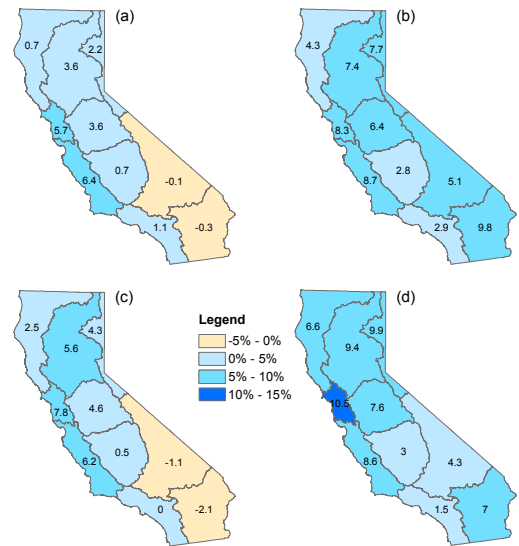
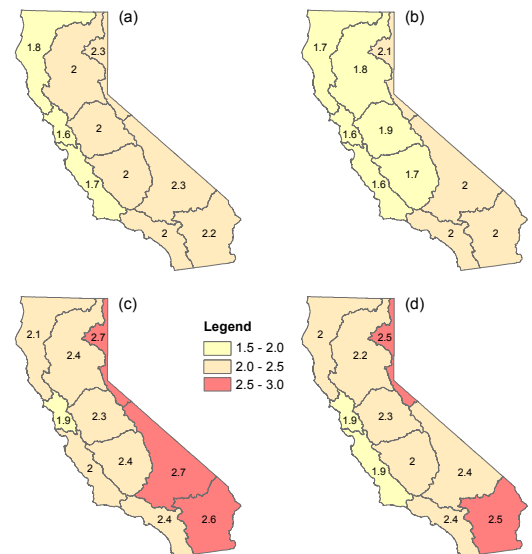


Figure 2. Differences (°C) between Historical and Mean Projections on Mean Annual (a) Maximum Temperature in Mid-century, (b) Minimum Temperature in Mid-century, (c) Maximum Temperature in Late Century, and (d) Minimum Temperature in Late Century.



Schwarz, A., P. Ray, S. Wi, C. Brown, M. He, M. Correa. 2018. Climate Change Risks Faced by the California Central Valley Water Resource System. California’s Fourth Climate Change Assessment. Publication number: CCCA4-EXT-2018-001.

Schwarz et al. (2018) analyzed climate change risks to the Central Valley System (Figure 3) which includes the California State Water Project and the federal Central Valley Project. By using a bottom-up decision scaling approach, starting with a systematic climate change stress test of the performance of the system to changes in temperature and precipitation, specific vulnerabilities to the system were identified. The study considered 1,100-year (reconstructed dendrochronology) record of Sacramento and San Joaquin River flows capturing a wide range of interannual variability, and evaluated vulnerabilities to low-frequency natural climate variability in concert with potential climate changes. This study was highlighted at the National Academies CCA4 workshop in August 2018 in Washington, DC.

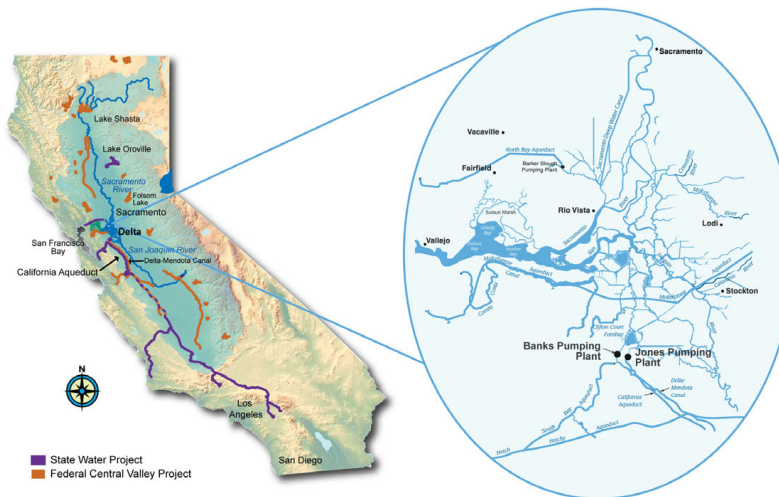


Figure 3. State Water Project and Central Valley Project in California (left). Sacramento-San Joaquin Delta (right).

As revealed by the study, because of climate change, the performance of the Central Valley Water system is likely to diminish significantly from historical levels of performance by 2050 in almost every category (e.g., supply, storage, Delta outflow). The likelihood of severely degraded future performance is especially high for north-of-Delta carryover storage and Delta exports. Table 1 below shows that the probability based on general circulation models (GCM) that mid-century performance will be inferior to current performance, considering both the Fifth Coupled Model Intercomparison Project (CMIP5) and CCA4 ensembles. In particular, the results show a 93 percent likelihood of diminished Delta exports in the future using GCM-based probability estimates and a 95 percent likelihood of diminished drought resilience and operational control for meeting downstream river flow temperature requirements in the future, using GCM-based probability estimates of future north-of-Delta reservoir carryover storage. Additional water will be required to be released from reservoirs or Delta exports will need to be reduced to maintain summer and fall regulatory conditions in the Delta resulting from increased sea levels and associated salinity intrusion.

Table 1. GCM-Based Probability that Mid-Century Performance will be inferior to Current Performance

Performance Metric	GCM-Based Probability that Mid-Century Performance will be inferior to Current Performance (Full CMIP5 Ensemble pdf)	GCM-Based Probability that Mid-Century Performance will be inferior to Current Performance (CCC4A Ensemble pdf)
<i>North-of-Delta Storage</i>		
Total NOD April Storage	65%	59%
Total NOD Carryover Storage	95%	95%
Shasta Carryover Storage	97%	97%
Oroville Carryover Storage	95%	95%
Folsom Carryover Storage	99%	99%
Trinity Carryover Storage	87%	86%
<i>Net Delta Outflow</i>		
Winter	63%	58%
Spring	65%	59%
Summer	21%	21%
Fall	40%	42%
Annual Delta Exports	93%	89%

1. CMIP5 (Taylor et al., 2012) 2. The subset of CMIP5 models that were recommended for use in the CCA4

Wang, J., H. Yin, E. Reyes, T. Smith, F. Chung. 2018. Mean and Extreme Climate Change Impacts on the State Water Project. California's Fourth Climate Change Assessment. Publication number: CCCA4EXT2018004.

Wang et al. (2018) also quantified climate change risks to California's State Water Project (SWP) and federal Central Valley Project (CVP) (Figure 3) but using a top-down approach that utilized the 20 climate change scenarios (10 global climate models and two emission scenarios, Representative Concentration Pathway [RCP] 4.5 and RCP 8.5) recommended by DWR's Climate Change Technical Advisory Group (also used for CCA4 studies in general). Water quantity and quality metrics such as Delta exports, North of Delta Carryover storage, reservoir dead storage (i.e. when reservoir levels fall below the lowest outlets), and Delta salinity were evaluated. For most of the climate change scenarios considered, loss in performance is projected in the future (Table 2).

Table 2. Change in Value of Performance Metrics for 20 CCTAG CMIP5 GCM Projections Compared to Base Scenario

CCTAG CMIP5 GCM Projection	Delta Export Change	Carryover Storage Change	Rim Inflow Change	Reliability Change*
ACCESS1_0_rcp45	-9%	-25%	-2%	-3%
ACCESS1_0_rcp85	-44%	-62%	-29%	-74%
CANESM2_r1p1i1_RCP45	12%	7%	31%	8%
CANESM2_r1p1i1_RCP85	21%	7%	52%	7%
CCSM4_r1p1i4_rcp45	-8%	-23%	4%	-9%
CCSM4_r1p1i4_rcp85	-4%	-20%	13%	-3%
CESM1-BGC_rcp45	-4%	-17%	-3%	-6%
CESM1-BGC_rcp85	-15%	-32%	-5%	-23%
CMCC-CMS_rcp45	-23%	-33%	-15%	-29%
CMCC-CMS_rcp85	-18%	-31%	-6%	-22%
CNRM-CM5_r1p1i1_rcp45	10%	-2%	36%	4%
CNRM-CM5_r1p1i1_rcp85	13%	-2%	45%	6%
GFDL-CM3_rcp45	-12%	-25%	-4%	-8%
GFDL-CM3_rcp85	-7%	-21%	3%	-3%
HadGEM2-CC_rcp45	-9%	-25%	7%	-16%
HadGEM2-CC_rcp85	-10%	-29%	2%	-13%
HadGEM2-ES_r1p1i1_rcp45	-16%	-30%	-5%	-26%
HadGEM2-ES_r1p1i1_rcp85	-37%	-55%	-19%	-68%
MIROC5_rcp45	-20%	-34%	-9%	-22%
MIROC5_rcp85	-27%	-41%	-12%	-32%
RCP8.5	-13%	-29%	4.6%	-22%
RCP4.5	-8%	-21%	4.2%	-11%

Note: CCTAG = California Department of Water Resources' Climate Change Technical Advisory Group, CMIP5 = Fifth Coupled Model Intercomparison Project, RCP = Representative Concentration Pathway; * A year with at least one dead storage month occurring. The system reliability for the base scenario is approximately 92.5 percent. A change of 0 percent indicates a reliability of 92.5 percent

The results showed that seasonal flow pattern shift in rim inflows from the Sierra Nevada and sea level rise in the San Francisco Bay together would exert overwhelmingly negative effects on south-of-Delta export, leading to a half million-acre feet export reduction in the middle of this century. The shifted seasonal flow due to earlier snow melting and more rain as precipitation is about two million-acre feet, causing more reservoir flood release and then higher Delta outflow in winter and early spring. This means meeting demand in summer will consume more carryover storage. This results in north-of-Delta carryover storage diminishing by 1.5-million-acre feet in the middle of this century. Besides reservoir carryover storage reduction, the occurrence of reservoir dead storage becomes potentially much more frequent due to higher variability of precipitation and flow, making the CVP/SWP system less reliable. Similarly, exported water and environmental water quality in the Delta would also worsen throughout the year in terms of "X2"¹ extending eastward as much as 4.5 kilometers, a result caused not only by sea level rise but also by the seasonal flow pattern shift in the middle of this century. The eastward shift means more water may be required for meeting water quality requirements and thus affecting SWP export.

Local Planning for Projected Climate Change Impacts

Five studies looked at various aspects of local planning for climate change impacts, three of which were specific to water management while the remaining two include applicable lessons for adaptation in the water sector.

Ekstrom, J.A., M.R. Klasic, A. Fencl, M. Lubell, E. Baker, F. Einterz. 2018. Drought Management and Climate Adaptation among Small, Self-Sufficient Water Systems in California. California's Fourth Climate Change Assessment, California Natural Resources Agency. Publication number: CCCA4-CNRA-2018-004.

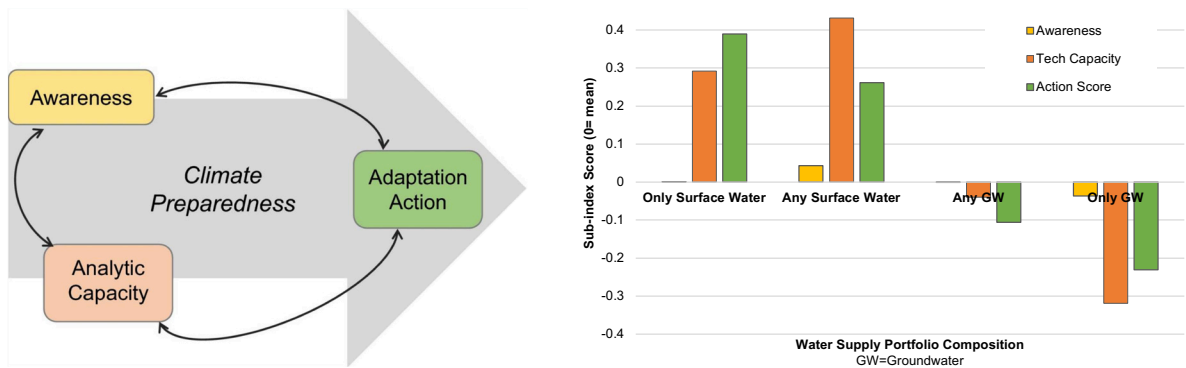
Under a changing climate, dry spells are projected to increase in frequency and duration in the Southwestern United States. Between 2012-2016, California experienced one of the region's worst droughts in its history with record high temperatures and record low snowpack, runoff, and precipitation. Documentation of experiences from an extreme event can inform future planning for droughts and more broadly highlight needs for climate adaptation. This study documents how small drinking water system managers were affected, responded, and challenged by the 2012-2016 Drought in California. The study included an analysis of perspectives and experiences of local water managers gathered through interviews, small regional workshops, and a statewide policy forum. Common disadvantages that hinder small drinking water system drought resilience, and similarly climate adaptation include: staff capacity; financial burden of revenue loss during drought compounded with increased demand on staff time for additional reporting; customer awareness and outreach challenges; and political disagreements over and physical limitations to consolidation to larger systems. More long-term in terms of planning for droughts under a changing climate, the lack of expressed concern and duty for climate change risks indicate a major scarcity in adaptation planning among small water systems.

Ekstrom, J.A., L. Bedsworth, and A. Fencl, 2017. Gauging preparedness for climate change impacts on water quality. Climatic Change 140(3-4):467-481.

Ekstrom et al. (2017) surveyed drinking water system managers across California as to what degree they have planned for climate change impacts on water quality. The study used 11 indicators to evaluate climate preparedness among water utilities, using survey response data. These indicators were organized into three indices capturing awareness of climate change, analytical capacity to adapt or otherwise manage for its impacts, and self-reported climate adaptation. The variables differed significantly by region and by water portfolio. For example, responses from the Central Valley showed lower overall preparedness, based on low analytical capacity and action. Alternatively, the South Coast and Bay Area stood out as more prepared than other regions. These regional differences may be driven by water source portfolios because the study also found that those systems with surface water had higher levels of analytic capacity and reported action than those relying only on groundwater (Figure 4). Across all respondents, trusted information sources most frequently used were State government agencies, followed by colleagues within their own utilities. The finding that frequently used sources of information are similar across utilities presents a promising opportunity for training and disseminating climate information to assist those systems needing the most support.

¹ X2 is the distance from the Golden Gate to the point where daily average salinity is two parts per thousand at one meter from the channel bottom.

Figure 4. Climate preparedness dimensions (left) summarized by water supply portfolio type (right).



Note: Some utilities are counted in more than one grouping because categories are not exclusive (e.g., a utility that has “only surface water” also fits in the category of “any surface water”).

Baker, E., J. Ekstrom, and L. Bedsworth, 2018. Climate information? Embedding climate futures within social temporalities of California water management. *Environmental Sociology* 4(4): 419-433.

This study analyzed the set of interviews with local water managers in California conducted in the above Ekstrom et al. (2018), but focused on how and whether water systems use climate change information. The Baker et al. (2018) study found the local water managers exhibit three different groupings in how they interact with climate science. Using sociological theory of “social futures,” the study describes these three groups as different cultural orientations of the future. One type is referred to as “modeled futures,” which includes those that view climate change as part of science, in that it can be incorporated into existing planning. The second type called “whose future” includes those who view and make use of climate change to defend or justify water management where social conflicts exist. A utility could fit into this type if it were to use climate change impacts to justify an infrastructure project that it already had in development, but selling it to customers as reducing climate change risk could be effective in gaining public support. The third type of water managers (“truncated futures”) view future climate as unpredictable and unknowable and therefore, unmanageable. This last group largely included those managing small water systems, which may explain some of the lack of reported climate adaptation actions found in the Ekstrom et al. (2017) survey described above.

Related Studies

Two studies focused on issues outside of the water sector offer additional insights that may inform future climate adaptation in DWR.

Ekstrom, J. and L. Bedsworth, 2018. Adapting air quality management for a changing climate: survey of local districts in California, *Journal of the Air & Waste Management Association*.

Ekstrom and Bedsworth (2018) examined local level management of air quality finding high awareness of climate change amongst managers, but a severe lack in planning for climate impacts in long-term air quality management, especially for extreme events. Neither federal nor state level policy incentivizes adaptation for air quality at the local level, which leaves managers to status quo planning. Documentation of this sector provides a comparison to the survey of local water managers conducted by Ekstrom, Bedsworth, and Fencil (2017), indicating that under supportive State agencies and policies, some local managers of drinking water are progressing in adaptation efforts. Therefore, this survey highlights that State agency efforts, like those of DWR, are important for triggering supporting local adaptation.

Moser, S.C., J.A. Ekstrom, J. Kim, S. Heitsch. 2018. Adaptation Finance Challenges: Characteristic Patterns Facing California Local Governments and Ways to Overcome Them. *California’s Fourth Climate Change Assessment, California Natural Resources Agency. Publication number: CCCA4-CNRA-2018-007.*

As resource managers advance in adapting to climate change, acquiring adequate funding is among the most frequently reported barriers impeding progress to preparing for climate change impacts. This study documents this challenge through a survey of local governments across California, and closely examines the barriers and innovations to financing and funding local adaptation efforts. It is likely there are or will be similar challenges among local water managers and those of other resources in California. Based on input gathered from interviews, a survey, and regional workshops, this study found that

distinct sets of challenges tend to occur together. Advancing adaptation, therefore, requires overcoming multiple barriers simultaneously rather than one at a time.

Implications for DWR

Several key messages arose from the DWR contributed studies that the Department and other water resource managers can use as they consider climate change in future planning, operations, and management. Key findings include:

- Compared to wet regions, dry regions are projected to have higher increases in temperature and more severe drought conditions;
- Sea level rise projections can and should be incorporated into flood management plans in the Delta;
- The State Water Project's south-of-Delta export and Oroville carryover storage are projected to be severely reduced by mid-century due to climate change impacts;
- Local small and/or groundwater-reliant water agencies are not preparing for climate change impacts, but larger systems are; and
- Small water systems need additional support with climate adaptation and this likely will require a different approach from what is provided to larger systems.

These DWR studies provide insights into climate change vulnerabilities and impacts on water management generally and DWR operations specifically, which can be useful in adaptation planning. Perhaps the most stark findings from the set of studies are that both Schwarz et al. (2018) and Wang et al. (2018) indicate a considerably reduced ability of this current SWP to provide water by mid-century. Schwarz et al. (2018) also demonstrates a process alternative to traditional climate change assessments, which evaluates risk from the decision-making perspective. Flooding projected in Maendly (2018) offers important information to formulate flood management plans that account for sea level rise and hydrology shifts.

The social science studies offered insights into local planning for climate adaptation. The study by Ekstrom et al (2018) on small systems found that existing policy, planning, and regulatory efforts are not robust enough to address administrative, financial, technical, and physical constraints encountered by small drinking water systems. Such water systems need additional support with climate adaptation. Similarly found in Baker et al. (2018), this could signal that the translation and distribution of climate change information and assistance to adapt to climate change may need to take different approaches to meet the needs for smaller water systems (e.g. different information translation and distribution avenues, types of presentations, guidance and/or technical assistance). These differences should be considered by DWR as it implements recent legislation (AB 1668) targeted to help small water systems and rural communities at risk to water shortage and drought.

Needs will change as climate adaptation processes advance and the water sector will likely encounter financial challenges to address the increasing needs to adapt to climate change. Moser et al.'s findings on understanding barriers to funding adaptation offer ways to begin financial planning now to avoid pitfalls that local governments are encountering.

The studies in the Fourth Assessment provide more certainty and higher resolution of how, when and where climate change will affect water resources in California. For instance, the findings from these studies point out the need to:

- 1) Make use of new climate change projections and other scientific advances in understanding atmospheric rivers, sea level rise, and other aspects of a changing climate in planning and operation. DWR is already investing in research to understand the dynamics of atmospheric rivers on California's water system, as well as to improve short-term flood forecasting.
- 2) Develop and evaluate potential adaptation strategies that address the risks posed by climate change. For instance, DWR could conduct risk-based analyses on different climate adaptation strategies to reduce wildfire risk in SWP watersheds. Additionally, DWR could evaluate the water year type definitions and whether revising the typology and the use of them could improve performance of the SWP within environmental regulatory requirements.

For more information about the articles cited in this summary, please email climatechange@water.ca.gov