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Water Use and Supply Concerns for Utility-Scale Solar Projects in the Southwestern United States

Geoffrey T. Klise, Vincent C. Tidwell, Marissa D. Reno, Barbara D. Moreland, Katie M. Zemlick, Jordan Macknick

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Abstract

As large utility-scale solar photovoltaic (PV) and concentrating solar power (CSP) facilities are currently being built and planned for locations in the U.S. with the greatest solar resource potential, an understanding of water use for construction and operations is needed as siting tends to target locations with low natural rainfall and where most existing freshwater is already appropriated. Using methods outlined by the Bureau of Land Management (BLM) to determine water used in designated solar energy zones (SEZs) for construction and operations & maintenance, an estimate of water used over the lifetime at the solar power plant is determined and applied to each watershed in six Southwestern states. Results indicate that that PV systems overall use little water, though construction usage is high compared to O&M water use over the lifetime of the facility. Also noted is a transition being made from wet cooled to dry cooled CSP facilities that will significantly reduce operational water use at these facilities. Using these water use factors, estimates of future water demand for current and planned solar development was made. In efforts to determine where water could be a limiting factor in solar energy development, water availability, cost, and projected future competing demands were mapped for the six Southwestern states. Ten watersheds, 9 in California, and one in New Mexico were identified as being of particular concern because of limited water availability.

Acknowledgements

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Executive Summary

Although a small fraction of current electric sector water use, solar energy development represents a particular concern as much of the existing and proposed development is occurring/planned for regions where water resources are approaching full utilization. The purpose of this project is to develop an improved understanding of water usage in relation to solar energy development in the southwestern U.S. This effort builds on prior studies in three specific ways: operational water needs will be extended to consider water for cleaning, potable facility needs, and short-term construction; availability of water for new development is mapped for five different sources in the southwestern U.S. along with the cost to access and treat each; and, projected water use for new solar development is combined with water availability/cost data to identify feasible water sources to help inform industry growth projections.

The first step in this analysis involved identifying existing and planned utility-scale solar projects and determining their water use. The Solar Energy Industries Association (SEIA) Major Solar Projects List[1] was used to gather information about the type of solar project as well as the locations of solar photovoltaic (PV) and concentrating solar power (CSP) facilities either operating, under development, under construction or cancelled. The *BLM PEIS Methodology* was utilized for estimating construction water usage, which is based on man-hour requirements for potable supply for the peak construction year, as well as evaporation rates (associated with dust suppression) in each Solar Energy Zone (SEZ). Similarly, the *BLM PEIS Methodology* was used to estimate operation and maintenance (O&M) water use based on a man-hour requirement for potable water needs and wash water use based on the size of the PV and CSP facility and evaporation losses associated with cleaning modules and mirrors. Operational water use for the facility, including water for cooling was also estimated using the *BLM PEIS Methodology*.

Potential water use was found to vary considerably by region. Specifically, for the 31 SEZ's initially considered by the BLM, total water required during construction ranges from 0.2 acre-feet/megawatt (AF/MW) (4,674 AF for a 17,043-MW Parabolic Trough plant) to 7 AF/MW (3,409 AF for a 508-MW PV plant). Total operational water use for a dry-cooled system could be as high as 2.16 AF/MW/yr (368 AF/yr for a 170-MW Parabolic Trough plant) to as low as 0.23 AF/MW/yr (2,864 AF/yr for a 12,300-MW Parabolic Trough plant), while a wet-cooled system ranged as high as 21.48 AF/MW/yr (3,656 AF/yr for a 170-MW Parabolic Trough plant) and as low as 1.63 AF/MW/yr (11,167 AF/yr for a 6,833-MW Power Tower). Total operational water includes water for panel/mirror washing, potable supply for the workforce, and cooling. In all cases, water use requirements during the peak construction year are likely to be greater than the average annual recharge to the basin but constitute a minor portion of current groundwater withdrawals and estimated groundwater storage in the basin.

In efforts to determine where water could be a limiting factor in solar energy development, water availability, cost, and projected future demand were mapped for the 17-conterminous states in the western U.S. Specifically, water availability was mapped according to five unique sources including unappropriated surface water, unappropriated groundwater, appropriated surface/groundwater,

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[1] http://www.seia.org/research-resources/major-solar-projects-list

municipal waste water, and brackish groundwater. Associated costs to acquire, convey and treat the water, as necessary, for each of the five sources were also estimated. To complete the picture, competition for the available water supply was projected over the next 20 years.

Mapping projected water demands with water availability over a solar facility estimated lifetime indicates some important mismatches. There is no availability of unappropriated surface water (permit or water right obtained directly from state) and limited availability of municipal waste water and unappropriated groundwater (permit or water right obtained directly from state) in watersheds with projected solar development. In contrast, brackish groundwater and appropriated water (water transferred from another use) is available in most developing basins. Many of the watersheds in California and Arizona will have to balance demands for solar development with that of rapidly growing demands in other water use sectors. Ten watersheds, 9 in California, and one in New Mexico were identified as being of particular concern because of limited water availability.

1. Introduction

1.1. Problem Statement

The water census conducted by U.S. Geological Survey (USGS) in 2005 (Kenny et al. 2009) estimated total freshwater withdrawals at 349 billion gallons per day (BGD). Of this, thermoelectric production accounted for 143 BGD or 41% of the total freshwater withdrawals making it the largest user of water, slightly ahead of irrigated agriculture (128 BGD at 37%). Total withdrawals have shown relatively little change since 1985 reflecting the trends in the two largest withdrawal sectors, thermoelectric power and irrigated agriculture (e.g., Hutson et al. 2005). In contrast consumptive water use for thermoelectric power production has shown steady growth, but only accounts for about 3.3% (3.3 BGD) of the U.S. total water consumption (Solley et al. 1995). Although a small fraction of electric sector water use, solar energy development represents a particular concern as much of the existing and proposed development is occurring/planned for regions where water resources are approaching full utilization (e.g., USACE 2012; Bureau of Reclamation 2010; Tetra Tech 2010).

In an effort to acknowledge and give due consideration to this solar energy-water nexus, initial efforts to quantify the amount of water required for major operational needs of utility-scale solar energy production facilities (i.e., cooling water) have been completed, documented (Macknick et al. 2011), and are being relied on as local, state, and federal decision-makers work to include solar technology in their strategic energy plans (Office of Senator Jon Kyle 2012). A complementary body of work exists in the metric developed by the Electric Power Research Institute (EPRI) that serves as an indicator for the susceptibility of U.S. counties to water supply constraints; this work in combination with solar production facility cooling water needs and an eye towards likely areas for concentrating solar power (CSP) develop has given rise to concern at the Federal level over where the cooling water will come from in a region increasingly defined by competing demands for an increasingly scarce resource (Congressional Research Service 2009).

Determining where cooling water supplies will come from is not only critical, but complex, as it requires an analysis of groundwater, surface water, and recycled water sources, as well as the legal and management constraints associated with obtaining water. Furthermore, the estimates of operational water needs that have been widely acknowledged might not capture the water challenge in its entirety, as construction, cleaning, and potable water supplies are also likely to pose a challenge to available supplies. To date, the most comprehensive body of technical work that addresses this water challenge is the *Final Programmatic Environmental Impact Statement (PEIS) for Solar Energy Development* (Bureau of Land Management [BLM] 2012). This study originally focused on 31 solar energy zones (SEZ) located in Arizona, California, Colorado, Nevada, New Mexico, and Utah, which were then reduced to 17 SEZs through the review process (Figure 1). According to the BLM, a SEZ is an area within their purvey that has a solar resource and transmission infrastructure well-suited for utility-scale solar production. The primary focus and value added by the PEIS study comes from the detailed analysis of the proposed development's impact on air, land, and water resources: air impacts focus on the potential for interference with military and civilian aviation; land impacts focus on the competing uses of realty, wilderness, livestock grazing, horse grazing, recreation, soil resources, mineral resources, geothermal resources and vegetation; water impacts include operation and construction water requirements, as well as wastewater generation.

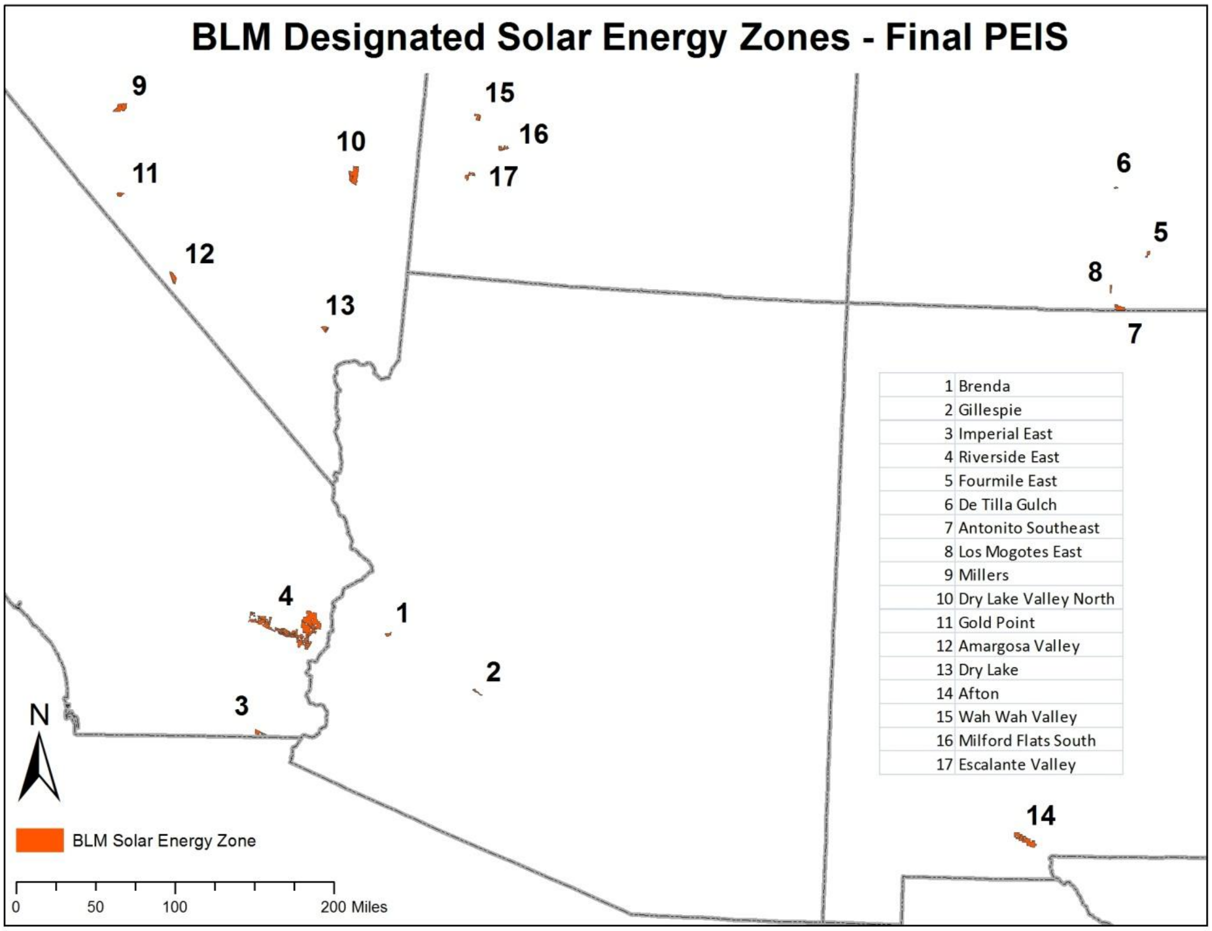

Figure 1. Locations of the 17 final BLM designated Solar Energy Zones.

The potential for water resource depletion and/or degradation is challenging the siting of utility-scale solar facilities in the desert southwest, as demonstrated by the following examples. Of the 14 SEZ's eliminated from further consideration, five specifically cited the potential for aquifer depletion as a result of groundwater pumping for wet cooling as part of the rationale to eliminate the SEZ while one cited the potential for significant water quality and watershed degradation. In October of 2010, the Arizona Corporation Commission granted Hualapai Valley Solar its certificate of environmental compatibility for a 340-MW concentrated solar plant outside of Kingman, Arizona with the prohibition that groundwater not be used as a cooling source, instead dry cooling or treated effluent must be used; as of May 2011, the construction of this plant was still stalled due to the financial burden that that the dry-cooling constraint had imposed (Adams-Ockrassa 2010; Adams-Ockrassa 2011). As of December 2012, according to research conducted by the Solar Energy Industries Association (SEIA), 10 proposed projects from 4 MW to 500 MW had been canceled and though no specific technical reason has been publically reported, an examination of these projects found that they were associated with unusually high water requirements (in relation to the over 500 operating or under-construction facilities).

1.2. Project Objectives

The purpose of this project is to develop an improved understanding of water in relation to solar energy development in the southwestern U.S. This effort builds on the aforementioned studies in three specific ways:

1. Power plant water use estimates will be expanded. Operational water needs will be extended to consider water for cleaning and potable needs. Additionally, water for short-term construction needs is estimated.
2. Availability of water for new development is mapped for the western U.S. Five different sources are considered including unappropriated surface water, unappropriated groundwater, appropriated water, municipal waste water and brackish groundwater. Costs to access and treat these different sources of water are also mapped.
3. Projected water use for new solar development is combined with water availability/cost data to identify feasible water sources to help inform industry growth projections.

Below, a detailed accounting of each of these tasks is given.

2. Water Use Estimates for Photovoltaic and Concentrated Solar Power Facilities

2.1. PV and CSP Facilities in the Southwestern U.S.

The SEIA Major Solar Projects List[2] was used to gather information about the type of solar project as well as the locations of solar PV and CSP facilities either operating, under development, under construction or cancelled. The SEIA data used for this analysis was current through November 5, 2012. Any changes to the status of an existing record in the List by SEIA, or additions made by SEIA between November 5,

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[2] http://www.seia.org/research-resources/major-solar-projects-list

2012 and the time of this publication are not captured in this analysis. The list has 512 entries, and was used as the base dataset for determining water use calculations. There were multiple locations without coordinates, and for those records an effort was made to determine the exact location of the project.

As the SEIA List captures a larger dataset of projects, including those in the planning stage and those under construction, there were many records remaining with no coordinates or additional data to support calculations of water use estimates. In these cases, supporting data published by Averyt et al. (2011) and UCS (2012) were utilized to fill in gaps in the SEIA List. Additional data gaps were filled from the *BLM PEIS Methodology*[3](discussed below), California Energy Commission (CEC) proceedings, project developer fact sheets and news reports. Figure 2 shows the location of the different PV facilities greater than 100MW and Figure 3 shows the location of all CSP facilities. The locations are plotted as a function of size and status.

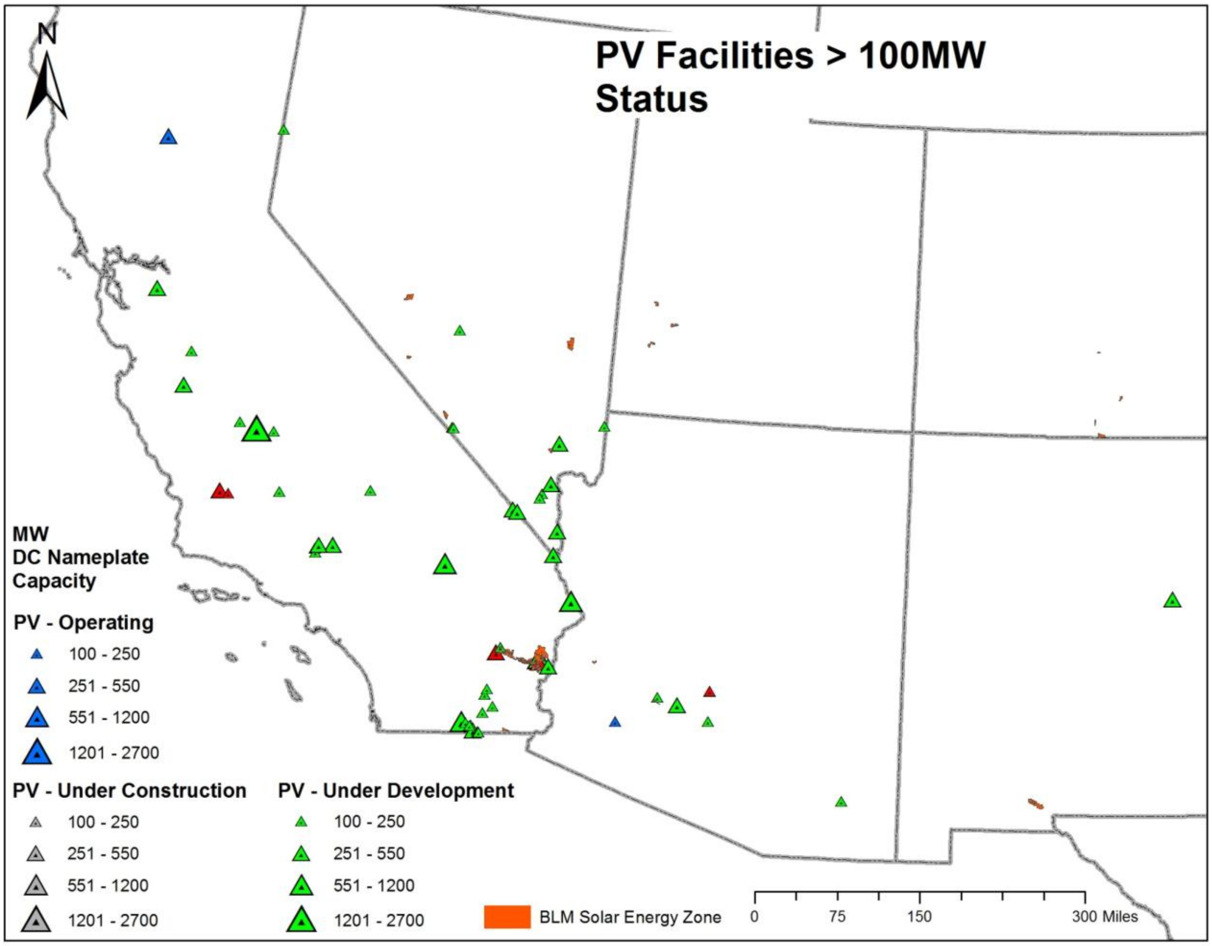

Figure 2. PV facilities greater than 100MW in California, Nevada, Arizona and New Mexico. Also shown are the BLM Solar Energy Zones.

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[3] http://solareis.anl.gov/

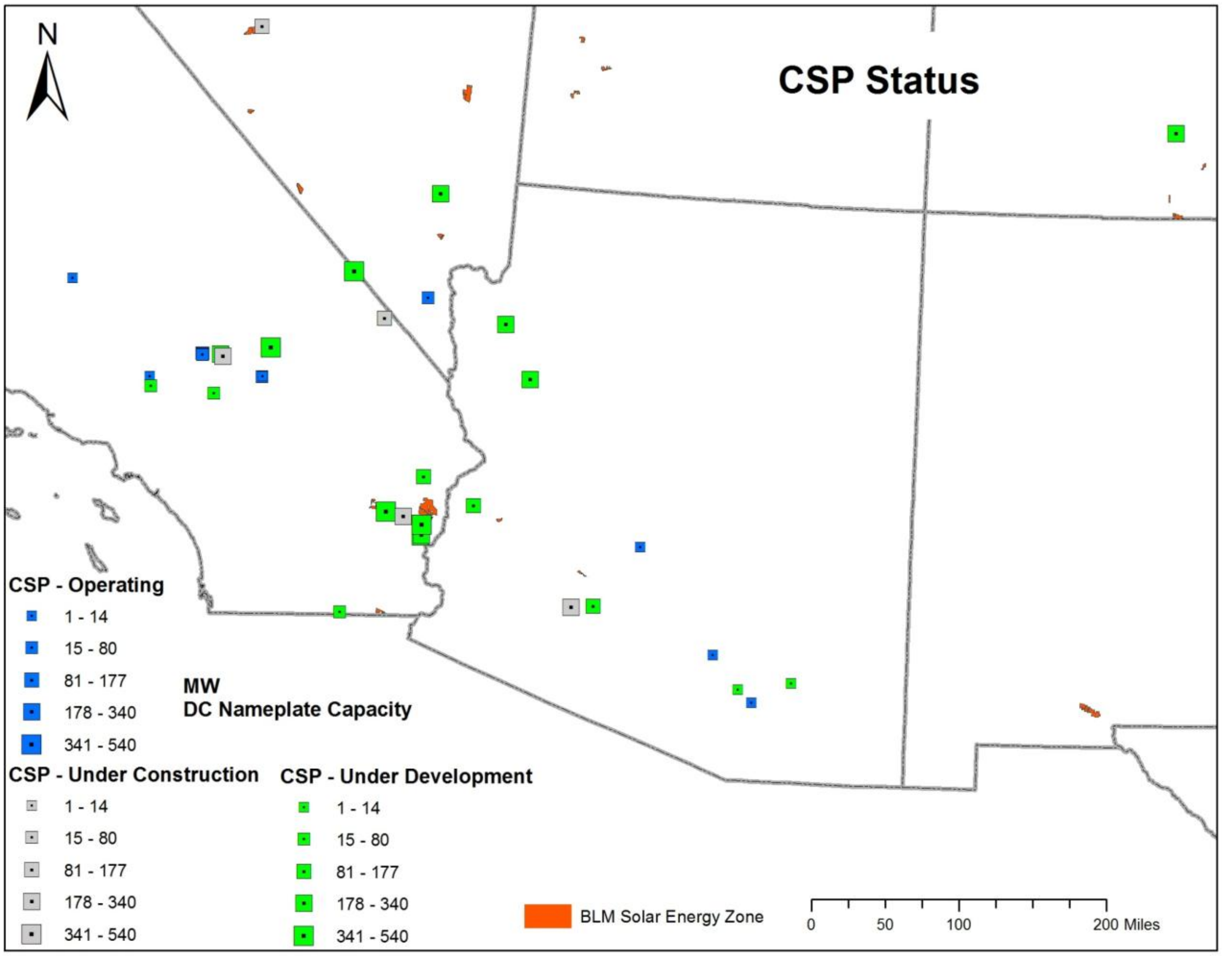

Figure 3. All CSP facilities (with data) in California, Nevada, Arizona and Colorado. Also shown are the BLM Solar Energy Zones.

The first step in estimating water use and consumption factors for utility-scale solar facilities was to look at the literature. The UCS (2012) database, from work by Averyt et al. (2011) using consumption factors by Macknick et al. (2011) was considered, as well as data from Burkhardt et al. (2011), however these approaches did not consider construction water usage, primarily dust control, and were not comprehensive enough to cover the entire range of construction and O&M water usage. The *BLM PEIS Methodology* was used in this analysis as it includes construction water use estimates and detailed operation and maintenance (O&M) water use estimates that are a function of the local evaporation rates and man hours necessary for performing certain tasks. The BLM data only considers specific SEZs for California, Nevada, Arizona, Utah, Colorado and New Mexico, thus a methodology was developed to extrapolate the construction and O&M water use estimates to the projects in the SEIA List that occur in these five states outside of the SEZs. Projects in these states represent 63% of the 512 entries in the SEIA List and are the focus of this study.

Efforts were made to compare the *BLM PEIS Methodology* water use estimates with previous work (Averyt et al. 2011; UCS 2012; Macknick et al. 2011; Burkhardt et al. 2011) and project estimated water use, where applicable.

2.2. Methodology for Developing Construction and O&M Water Use Estimates for PV Facilities

In the data provided by Averyt et al. (2011) and UCS (2012), with water use factors by Macknick et al. (2011), consumption factor estimates for solar PV range from 0 to 33 gallons/MWh, with a median value reported at 26 gallons/MWh. These factors were considered for determining O&M water use for the expanded database, however in order to calculate water consumption, an estimate of the electricity generation is necessary, and this data was not readily available. In addition, PV systems don't require active cooling like traditional power plants, with O&M water use only for washing panels and potable usage for those monitoring activities at the site. It follows that calculating O&M usage would be more accurate as a function of the total *size* of the PV power plant (number of modules, or area covered) rather than the production output in units such as MWh/yr. For these reasons, the approach developed in the *BLM PEIS Methodology* was utilized as it represents the most current research on water use estimates for large utility-scale PV facilities. There are a few cases where estimates are made based on generation to allow for a comparison between PV and CSP facilities. It should be noted that these estimates using BLM data cannot be truly validated until large facilities are built, and water use data is reported to the BLM, the US Energy Information Administration (EIA) or other agencies.

The methodology developed by the BLM is used in this report and compared to previous research on water used by solar power plants (Averyt et al. 2011; UCS 2012; Macknick et al. 2011; Burkhardt et al. 2011). The specific water use data was gathered from the water use estimates within each *approved* SEZ, as the boundaries and area of some SEZs changed between compiling the draft and final PEIS, with some SEZs being removed entirely.

<u>Construction Estimates of Water Use</u>

Construction water use estimates were determined based on man-hour requirements for potable supply for the peak construction year, as well as evaporation rates in each SEZ. Assumptions and multipliers used by the BLM can be found in Appendix M, Section M.9.2 and Table M.9-2 in the Draft Solar PEIS (BLM 2010). These estimates include water use only with no chemical stabilizers for dust control. The SEZ data was converted to AF/MW by taking each individual SEZ value for peak build out (assuming all PV plants) and dividing by the final "Assumed Maximum SEZ Output" (in MW) for PV systems, which factors in the estimated PV facility size of 9 acres/MW (BLM 2010). There are no detailed assumptions by the BLM on the footprint of concentrating photovoltaics (CPV) facilities for construction water use, therefore considering that CPV facilities will have a smaller footprint per MW than PV facilities, the estimates used here will likely overestimate construction water use. This impacts 15 CPV facilities compiled in the extended database. However, the analysis presented later only considers PV facilities greater than 100 MW, so these CPV facilities (all under that size) were not considered in this analysis.

As the estimates in Table 1 consider the evaporation rates in each SEZ, there will be differences in the dust control estimates. It should be noted that the estimates in this table for construction are for peak water use. As these large facilities may take multiple years for full build-out, non-peak water use will likely be less than what is shown in the Table 1. For this analysis, it was estimated that construction water use for subsequent years is 30% of the peak value. Unfortunately, the BLM data did not have an estimate for water use in non-peak construction years (a discussion of this assumption as compared to an approved project on BLM land is presented below in the 'validation of methodology' section).

The time estimated for construction was based on a relationship between existing PV facilities greater than 25 MW (to filter out large commercial systems) with "Start Construction" and "Online Date" published in the SEIA List. In some cases, the "Expected Online Date" was used to capture the time frame for the largest projects that have a nameplate capacity greater than any PV project built to date. This relationship was used to estimate the time for build-out for other PV facilities that did not have data reported in the "Start Construction" and "Online Date" fields.

This data was then brought into the expanded database with total construction water use estimates in AF/yr calculated for each of the 276 PV projects in the six-state area using the following method:

- For year one:

$$PV\ Const_{peak} \times NC$$

- Between 1 and 1.99 years:

$$NC \times \left(PVconst_{peak} + \left(0.30 \times PVconst_{peak} \times Yr_{Fraction\ b/t\ 1\ to\ 1.99}\right)\right)$$

- Greater than 2 years (n and n+0.99) e.g., 3 and 3.99:

$$NC \times \left(PVconst_{peak} + \left(n \times 0.30 \times PVconst_{peak}\right) + \left(0.30 \times PVconst_{peak} \times Yr_{Fraction\ b/t\ n\ to\ n\ +\ 0.99}\right)\right)$$

Where:

NC = Nameplate Capacity in Megawatts (MW)
$PVconst_{peak}$ = peak construction water use in AF/MW
0.30 = percentage applied to reduce peak water usage
$Yr_{Fraction\ b/t\ 1\ to\ 1.99}$ = fraction of year between 1 to 1.99 for projects between 1 and 1.99 years,
$Yr_{Fraction\ b/t\ n\ to\ n\ +\ 0.99}$ = fraction of year between n to n + 0.99 for projects greater than 2 (n) years.

O&M Estimates of Water Use

To determine estimates for O&M usage, including module washing and potable supply, data from the *BLM PEIS Methodology* was utilized to determine water use factors that are based on a man-hour requirement for potable water needs and water use based on the size of the PV facility and evaporation losses that will occur when cleaning the modules. Assumptions and multipliers used by the BLM can be found in Appendix M, Table M.9-2 in the Draft Solar PEIS (BLM 2010). The SEZ data was converted to AF/MW by taking each individual SEZ value (assuming all PV plants) and dividing by the final "Assumed Maximum SEZ Output" for PV systems, which factors in the estimated plant size of 9 acres/MW. Values reported in this analysis represent the average value calculated from a BLM reported 'low' and 'high' value.

This data was then brought into the expanded database, with total O&M water use estimates in AF/yr calculated for each of the 276 PV projects in the six-state area using the following equation:

$$PV\ O\&M_{total} \times NC$$

Where:

$PV\ O\&M_{total}$ = Total PV O&M Water Usage in AF/MW/Yr

NC = Nameplate Capacity in MW

Table 1. PV Construction Water Use Estimates

State	Solar Energy Zone (SEZ)	Construction Water Use AF (peak)			O&M Water Use AF/yr		
		Dust Control	Potable Supply	Total Water Use	Module Washing	Potable Supply	Total Water Use
Arizona	Brenda & Gillespie[i]	5.6428	0.0284	5.6880	0.0509	0.0023	0.0532
California	Imperial East & Riverside East[ii]	2.2510	0.0099	2.2609	0.0496	0.0016	0.0511
Colorado	Antonito Southeast, DeTilla Gulch, Fourmile East, LosMogotes East[iii]	2.3300	0.0248	2.3548	0.0510	0.0050	0.0513
New Mexico	Afton[iv]	1.3109	0.0071	1.3181	0.0499	0.0011	0.0511
Nevada	Armargosa Valley, Dry Lake, Dry Lake Valley North, Gold Point, Millers[v]	2.5815	0.0146	2.5961	0.0504	0.0016	0.0520
Utah	Escalante Valley Milford Wah Wah Valley[vi]	2.1930	0.0163	2.2105	0.0513	0.0014	0.0527

i – Data from http://solareis.anl.gov/documents/fpeis/Solar_FPEIS_Volume_2.pdf

ii – Data from http://solareis.anl.gov/documents/dpeis/Solar_DPEIS_California_SEZs.pdf & http://solareis.anl.gov/documents/fpeis/Solar_FPEIS_Volume_2.pdf

iii – Data from http://solareis.anl.gov/documents/fpeis/Solar_FPEIS_Volume_3.pdf & http://solareis.anl.gov/documents/dpeis/Solar_DPEIS_Colorado_SEZs.pdf

iv – Data from http://solareis.anl.gov/documents/dpeis/Solar_DPEIS_Nevada_SEZs.pdf & http://solareis.anl.gov/documents/fpeis/Solar_FPEIS_Volume_4.pdf
v - Data from http://solareis.anl.gov/documents/dpeis/Solar_DPEIS_Utah_SEZs.pdf & http://solareis.anl.gov/documents/fpeis/Solar_FPEIS_Volume_5.pdf
vi – Data from http://solareis.anl.gov/documents/fpeis/Solar_FPEIS_Volume_5.pdf

Comparison of Methodology for PV Facilities

An effort was made to compare the estimates using the *BLM PEIS Methodology* with other datasets, including Averyt et al. (2011) and UCS (2012), along with project-specific estimated water usage. Until actual project construction water use is made available for analysis, it will be difficult to validate these estimates.

Checking the value of the estimates from construction water used, estimates in the Stateline Solar Farm (California) Project Draft EIS were compared to the calculated construction estimates. According to this EIS, "Approximately 1,900 acre-feet (ac-ft) of water would be needed during the approximately 2 to 4 year construction period, with the majority (approximately 1,045 ac-ft) of the construction water use occurring during the site preparation period of the first year" (BLM November 2012b Pg 4.19-2). This estimates the total non-peak water use at 45% of the peak water usage. Comparing our estimate described above, based on the *BLM PEIS Methodology*, the 300 MW facility build-out is estimated at 2.4 years, with total water usage at Stateline Solar Farm estimated at 1166 acre-feet. If the construction time is estimated at 3 years, this would result in 1900 acre-feet, and at 4 years, around 2300 acre-feet. These results calculated using the *BLM PEIS Methodology* are consistent with the BLM estimate for Stateline at 1900 acre-feet for the 2-4 year period, assuming their calculations were based off of a 3-year construction scenario. The comparison also suggests that for this facility, the estimate used for analyzing construction water use at all PV facilities at 30% of the peak construction year may be too low, with results underestimating construction water usage. More research into actual construction water usage as these facilities are built will help determine actual peak and non-peak water usage.

The O&M estimate for the Stateline Solar Farm project using the *BLM PEIS Methodology* is approximately 15 AF/yr. According to the BLM, estimated O&M water use is 20 AF/yr, only for sanitary purposes. At this location, the applicant (Desert Stateline, LLC) claims there will be *no* washing of the modules (BLM 2012b, pg 2-6; 2-14). Over the stated 30 year lifetime of this project, these estimates include a range of 460 to 600 AF, respectively, which are 24% and 32% of the construction water usage of 1900 AF. These results suggest whether or not module washing occurs during the lifetime of the PV power plant, construction water use is a large component of the total water needs at the site.

Comparing the 16 existing PV facilities identified in the Averyt et al. (2011) study in the six-state area to the O&M estimates using the *BLM PEIS Methodology*, the estimates using EIA data (Averyt et al. 2011) are higher than the *BLM PEIS Methodology* estimate in 7 out of 16 facilities by an average of 0.102 AF/yr, and those using the *BLM PEIS Methodology* are higher than the EIA data in 9 out of 16 facilities with an average of 0.041 AF/yr. One of the largest facilities (14 MW) calculated by Avyert et al. (2011) was estimated at 3.29 AF/yr while the same facility estimated using the *BLM PEIS Methodology* is estimated at 25.20 AF/yr. This is an 87% difference, while the differences in the smaller existing facilities ranged between 11 and 99%. Differences in these estimates are likely due to whether the facility is a commercial or utility scale PV system. The BLM envisions large-scale utility projects in the 100 MW and greater range in arid, rural locations. Applying the BLM estimates to systems smaller than 100 MW may end up in some cases overestimating O&M, especially panel washing in areas where dust is not as much of an issue and cleaning is done less frequently. However there are many small-scale utility owned systems well under 100 MW that are located in areas where dust is a concern. Due to the uncertainty in location for smaller PV facilities, where large commercial systems in an urban area may require less water use for washing than smaller utility scale systems in arid, rural locations where dust is a concern, the analysis presented in the next section considers only PV systems 100 MW or greater to be consistent with the BLM estimates for facilities that are primarily located in rural, undeveloped areas of high solar insolation and low rainfall.

2.3. PV Facilities - Estimated Water Consumption Discussion

The data above were consolidated and results shown below limited to only 100 MW and larger PV facilities, which represents 60 out of 262 facilities, or 23% of the PV facilities in the six-state area analyzed in the expanded database. The Total Construction and Total 25-year O&M water use for facilities greater than 100 MW is shown in Figure 4 for the six states. Colorado has no projects that are in this size range, and New Mexico, Nevada and Utah have no existing projects or projects under construction in this size range, though there are projects this size and larger under development.

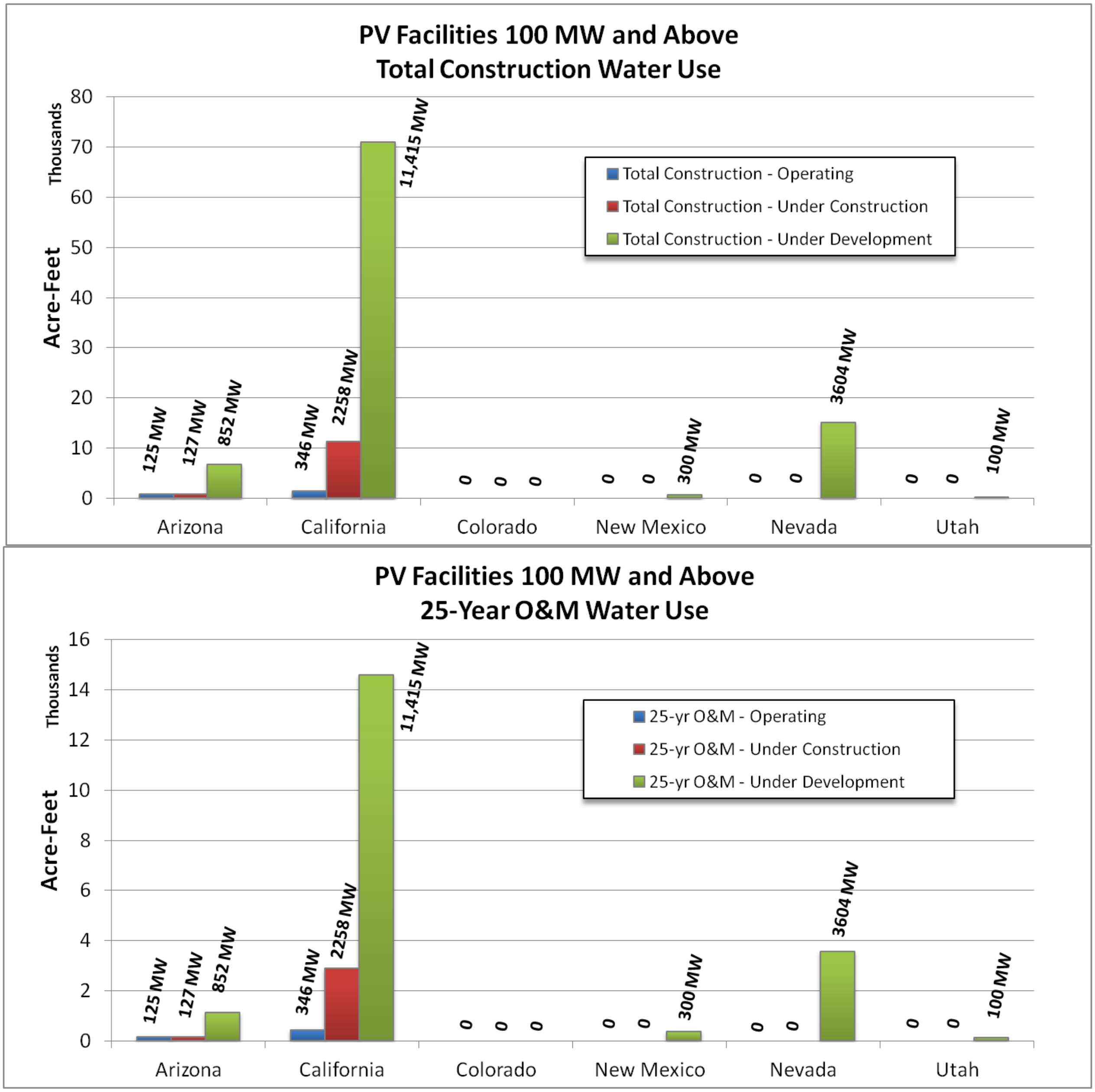

Figure 4. Construction and O&M water use estimates (consumption) for 100 MW and larger PV facilities in the six-state area. The total nameplate capacity represented by the different status categories is also shown.

A comparison between the construction and 25-year O&M water use in California is shown in Figure 5, with results indicating that O&M for projects in all phases (operating, under construction or under development) is on average approximately 25% of the total construction water use. The calculated water intensity in the construction period is much greater than any calculated O&M water use estimates over a 25-year project lifetime. Some projects may only operate for 20 or 25 years, depending on the power purchase agreement (PPA) attached to that facility. Considering the different PPA terms, the calculated O&M water usage may be less or similar to the 25-year estimates presented here; however the calculated construction water use should not change if it is the only method utilized for dust control.

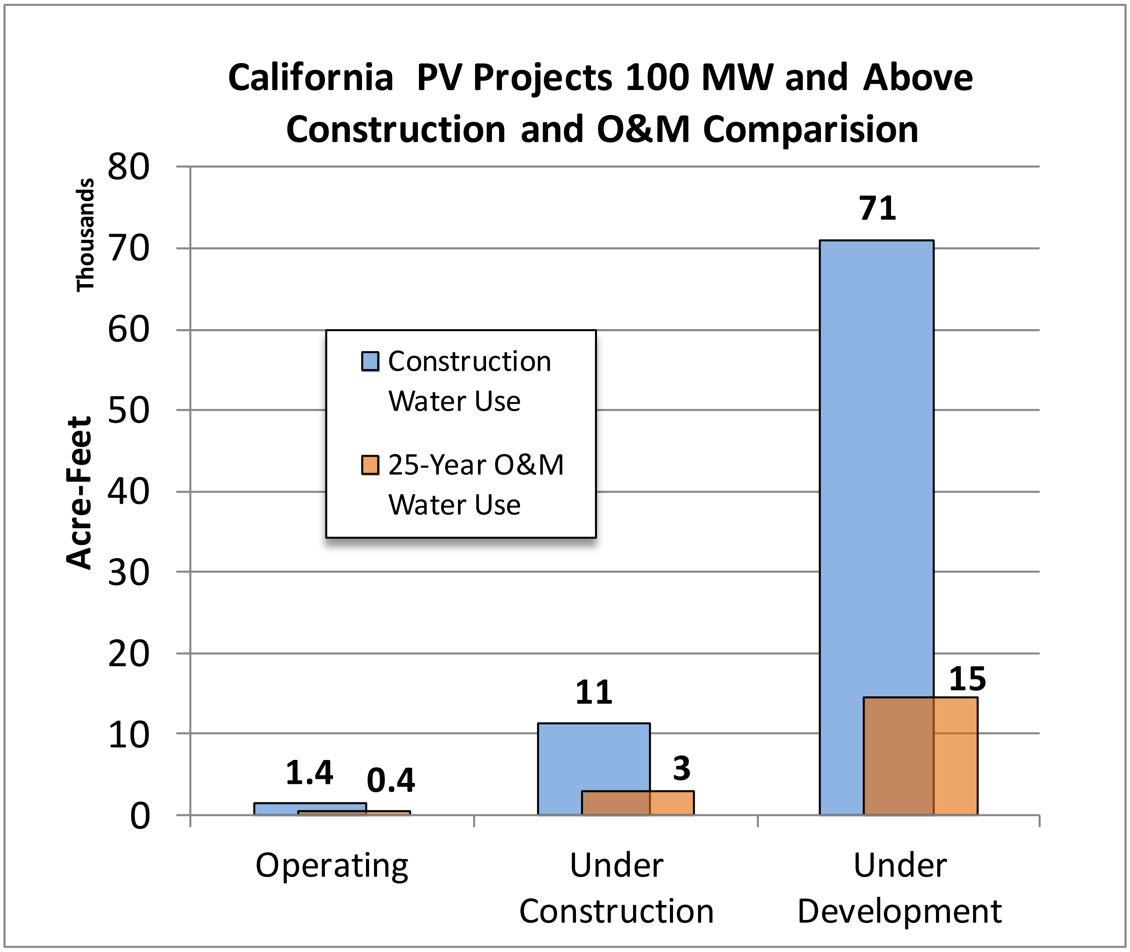

Figure 5. California construction and O&M water use estimates for 100 MW and larger PV facilities.

2.4. Methodology for Developing Construction and O&M Water Use Estimates for CSP Facilities

The *BLM PEIS Methodology* was used to determine the construction water use estimates for trough, power tower and dish engine CSP facilities. Water use factors by Macknick et al. (2011) were used to determine O&M water use estimates for the CSP facilities. In the six-state area, this represents a total of 40 facilities in different stages of operation, construction and planning. The specific water use data was gathered from each *approved* SEZ as the boundaries and area of some SEZs changed between compiling the draft and final PEIS, with some SEZs being removed entirely.

Table 2. CSP Construction Water Use Estimates

State	Solar Energy Zone (SEZ)	Trough[i] Construction Water Use AF (peak)			Power Tower[ii] Construction Water Use AF/Yr (peak)			Dish Engine[ii] Construction Water Use AF/Yr (peak)		
		Dust Control	**Potable Supply**	**Total Water Use**	**Dust Control**	**Potable Supply**	**Total Water Use**	**Dust Control**	**Potable Supply**	**Total Water Use**
Arizona	Brenda & Gillespie[i]	2.6556	0.1573	2.8129	5.6428	0.1336	5.7786	5.6428	0.0564	5.6992
California	Imperial East & Riverside East[ii]	0.8329	0.0451	0.8780	2.2510	0.0494	2.3004	2.2510	0.0208	2.2718
Colorado	Antonito Southeast, DeTilla Gulch, Fourmile East, LosMogotes East[iii]	1.1750	0.1413	1.3163	2.3300	0.1143	2.4444	2.3300	0.0461	2.3761
New Mexico	Afton[iv]	0.4856	0.0309	0.5165	1.3109	0.0338	1.3447	1.3109	0.0139	1.3248
Nevada	Armargosa Valley, Dry Lake, Dry Lake Valley North, Gold Point, Millers[v]	0.9383	0.0645	1.0028	2.5815	0.0720	2.6534	2.5815	0.0302	2.6116
Utah	Escalante Valley Milford Wah Wah Valley[vi]	0.8129	0.0745	0.8875	2.1930	0.0815	2.2745	2.1930	0.0344	2.2274

i – Trough area assumed by BLM at full build out is 5 acres/MW (BLM 2010).
ii – Power Tower and Dish Engine area assumed by BLM at full build out is 9 acres/MW (BLM 2010).

Construction Estimates of Water Use

Construction water use estimates were calculated based on man-hour requirements for potable supply for the peak construction year, as well as evaporation rates in each SEZ. Assumptions and multipliers used by the BLM can be found in Appendix M, Section M.9.2 and Table M.9-1 in the Draft Solar PEIS (BLM 2010). These estimates include water use only with no chemical stabilizers for dust control. The SEZ data was converted to AF/MW by taking each individual SEZ value for peak build out (assuming all CSP plants) and dividing by the final "Assumed Maximum SEZ Output" (in MW) for the different types of CSP facility footprints, which factors in the estimated plant size of either 5 or 9 acres/MW, depending on the type of CSP facility (BLM 2010).

As the estimates in Table 2 consider the evaporation rates in each SEZ, there will be differences in the amount estimated for dust control by state. It should be noted that the estimates in this table for construction are for peak water use. As these large facilities may take multiple years for full build-out, non-peak water use will likely be less than what is shown in the Table 2. For this analysis, it was estimated that construction water use for subsequent years is 30% of the peak value, which is the same assumption used above for estimated construction for PV facilities. Unfortunately, the BLM data does not have an estimate for water use in non-peak construction years (a discussion of this assumption as compared to an approved project on BLM land is presented below in the 'validation of methodology' section).

The time estimated for construction was based on a relationship between existing CSP facilities with "Start Construction" and "Online Date" published in the SEIA List. In some cases, the "Expected Online Date" was used to capture the time frame for the largest projects that have a nameplate capacity greater than any CSP project built to date. This relationship was used to estimate the time for build-out for other CSP facilities that did not have data reported in the "Start Construction" and "Online Date" fields. As there were not as many CSP facilities with date information, the following assumptions were used: For projects less than 50 MW, construction is assumed to take 1 year. For 51 MW to 150 MW, 2 years. For 151 MW to 300 MW, 2.5 years. For 301 MW and higher, 3 years. These values may overestimate for some and underestimate for others as there is no exact linear relationship between the size of the facilities and construction duration. As more projects are completed and water use reported, more detailed information will be available to refine these estimates.

This data was then brought into the extended database, with total construction water use estimates in AF/yr calculated for each of the 40 CSP projects in the six-state area using the following equation:

- For year one:

$$CSP\ Const_{peak} \times NC$$

- For 2 years:

$$NC \times \left(CSP\ const_{peak} + \left(0.30 \times CSP\ const_{peak}\right)\right)$$

- For 2.5 years:

$$NC \times \left(CSP\ const_{peak} + \left(0.30 \times CSP\ const_{peak}\right) + \left(0.30 \times 0.50 \times CSP\ const_{peak}\right)\right)$$

- For 3 years:

$$NC \times \left(CSP\ const_{peak} + \left(2 \times 0.30 \times CSP\ const_{peak}\right)\right)$$

Where:

$CSP\ Const_{peak}$ = Peak year construction water use in AF/MW
NC = Nameplate Capacity (MW)
0.30 = Applied to reduce peak water usage (30%)

0.50 = half year for 2.5 year duration analysis
2 = second and third year of non-peak use analysis for 3-year project

O&M Estimates of Water Use

To determine estimates for O&M usage, data in Averyt et al. (2011) and UCS (2012) using the Macknick et al. (2011) water consumption factors was used and compared to estimates using the *BLM PEIS Methodology*. The *BLM PEIS Methodology* data had enough granularity to determine consumption for mirror washing, potable use and water used in the cooling process on a yearly basis. The one thing lacking in the BLM methodology was an estimate for water consumption for hybrid cooling. Data as reported using the Macknick et al. (2011) consumption factors only reports the total O&M usage per year.

Assumptions and multipliers used by the BLM can be found in Appendix M, Table M.9-2 in the Draft Solar PEIS (BLM 2010). The SEZ data was converted to AF/MW by taking each individual SEZ value for peak build out (assuming all CSP plants) and dividing by the final “Assumed Maximum SEZ Output” (in MW) for the different types of CSP facility footprints, which factors in the estimated plant size of either 5 or 9 acres/MW, depending on the type of CSP facility (BLM 2010).

This data was then brought into the expanded database, with total O&M water use estimates in AF/yr calculated for each of the 46 CSP projects in the six-state area using the following equation:

$$CSP\ O\&M_{total}\ \times NC$$

Where:

$CSP\ O\&M_{total}$ = Annual Operation and Maintenance water use in AF/MW/yr
NC = Nameplate Capacity (MW)

Data is available to calculate mirror washing, and a few examples are shown in the validation section below, however the data calculated here is primarily for total O&M to allow for a comparison between the *BLM PEIS Methodology*, Macknick et al. (2011) consumption factors, and project reported data. Results are shown below in the comparison section.

Factors from Macknick et al. (2011) were multiplied by the annual generation in MWh/yr, to get a resulting O&M estimate for the facility in AF/yr.

Comparison of Methodology for CSP Facilities

An effort was made to compare the estimates using the *BLM PEIS Methodology* with other datasets, including Macknick et al. (2011), Burkhardt et al. (2011) and project estimated water usage. Until actual project construction water use is made available for analysis, it will be difficult to validate these estimates.

For the construction estimates, a few CSP Tower projects were compared using the *BLM PEIS Methodology* with project reported data. For CSP Trough projects, we were also able to compare with

Burkhardt et al. (2011). As shown in Table 3, for two sites, the *BLM PEIS Methodology* underestimates the project reported construction water usage. The Genesis site in California is well under the project estimated usage as stated in the CEC final decision (CEC 2010).

The values reported by Burkhardt et al. (2011) are based on a hypothetical 103 MW facility, and define construction water use as "activities associated with site improvements, transporting components to the site, and plant assembly." Dust control is not specifically called out in their analysis, and comparing a few trough facilities with the *BLM PEIS Methodology* indicates the Burkhardt et al. (2011) methodology at around 5% to 17% of the *BLM PEIS Methodology* in terms of total construction water use.

Table 3. CSP Construction Water Use Comparisons

Project Name	Type	Size (MW)	Generation (MWh/yr)	Project Reported (AF)	**BLM PEIS (AF)**	Burkhardt et al. (2011) (AF)[i]
Quartzite - Arizona	Tower	100	500,000	1150	**751**	N/A
Genesis – California	Trough	250	600,000	1848	**318**	40
Solana – Arizona	Trough	280	903,000	N/A	**1142**	60

i – Burkhardt et al. (2011) estimates were converted from L/kWh to AF using the estimated 1-year generation and multiplied by the estimated number of years for construction.

For O&M Water use, there are multiple methodologies that are used for comparison (Table 4) with the lowest values calculated from using the Macknick et al. (2011) methodology (median value) and the highest values using the *BLM PEIS Methodology* (average value). The Burkhardt et al. (2011) method has two different O&M estimates. Based on the "Operational" definition of O&M by Burkhardt, this value is more appropriate to compare to the other estimates as the full O&M estimate considers usages not considered in other O&M estimates, such as manufacturing water use, transportation for replacement components, and fuel consumption by on-site vehicles. For comparison purposes, the entire O&M estimate by Burkhardt et al. (2011) is shown in Table 4. These results for trough facilities show a much tighter range in estimates for both wet and dry cooled, at +- 30% of the Project Developer Estimated water use (as reduced by the CEC) for the Genesis system and +30% and -6% of the projected Developer Estimated water use for the Mojave system. The Burkhardt Operational estimate was the closest to both Project Reported estimated water usage at -10% for the Genesis facility and +3% for the Mojave site.

Table 4. CSP O&M Water Use Comparisons

Project Name	Type	Size (MW)	Generation (MWh/yr)	O&M Project Reported (AF/yr)	**O&M BLM PEIS (AF/yr)**	O&M Macknick et al. (2011) (AF/yr)[i]	O&M *All* Burkhardt et al. (2011) (AF/yr)[i]	O&M *Operational* Burkhardt et al. (2011) (AF/yr)[ii]
Saguache - Colorado	Tower-hybrid	200	900,000	300	**222**	72	N/A	N/A

Crescent Dunes - Nevada	Tower-hybrid	110	500,000	600	**124**[iii]	261	N/A	N/A
Genesis – California	Trough-Dry	250	600,000	202	**279**	144	268	182
Mojave - California	Trough-wet	280	903,000	1700	**2504**	1593	2043	1751
SEGS 1-9 – California	Trough - wet	354	654,544	N/A	**3544**	1738	2229	1910

i – Based on median value.
ii – Burkhardt et al. (2011) estimates were converted from L/kWh to AF using the estimated 1-year generation.
iii – Used dry cooling as BLM did not have hybrid cooling estimate.

The existing SEGS 1 though 9 facilities were analyzed for O&M water usage using the three methodologies (Table 4). The database in UCS (2012) is much lower than the average generation values reported for 1991-2002.[4] Considering the long-term generation average from 1991-2002 for all 9 plants, The values for Macknick et al. (2011) and Burkhardt et al. (2011) were in close agreement, while the *BLM PEIS Methodology* values were around 2x higher.

A look at mirror washing as compared to total O&M water use was made using Project Reported, the *BLM PEIS Methodology* and Macknick et al. (2011). The results in Table 5 show that for this dry cooled Tower facility in Arizona, the Project Reported and *BLM PEIS Methodology* for mirror washing alone are greater than the total estimated O&M using Macknick et al. (2011).

Table 5. CSP O&M Total Compared to Mirror Washing – Quartzite Arizona

Project Name	Type	Total O&M Project Reported (AF/yr)	**Mirror Washing Project Reported (AF/yr)**	Total O&M BLM PEIS (AF/yr)	**Mirror Washing BLM PEIS (AF/yr)**	**Total O&M Macknick et al. (2011) (AF/yr.)**
Quartzite - Arizona	Tower	200	**70**	111	**50**	**40**

2.5. CSP Facilities - Estimated Water Consumption Discussion

The data above for construction and O&M as calculated using the *BLM PEIS Methodology* was consolidated and results shown below consider all 40 CSP facilities, regardless of size, in the six-state area. The Total Construction and Total 25-year O&M water use, along with total MW nameplate capacity is shown in Figure 6 for the six states. Colorado only has projects Under Development, while New Mexico and Utah have no CSP projects Operating, Under Construction or Under Development.

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[4] http://en.wikipedia.org/wiki/Solar_Energy_Generating_Systems

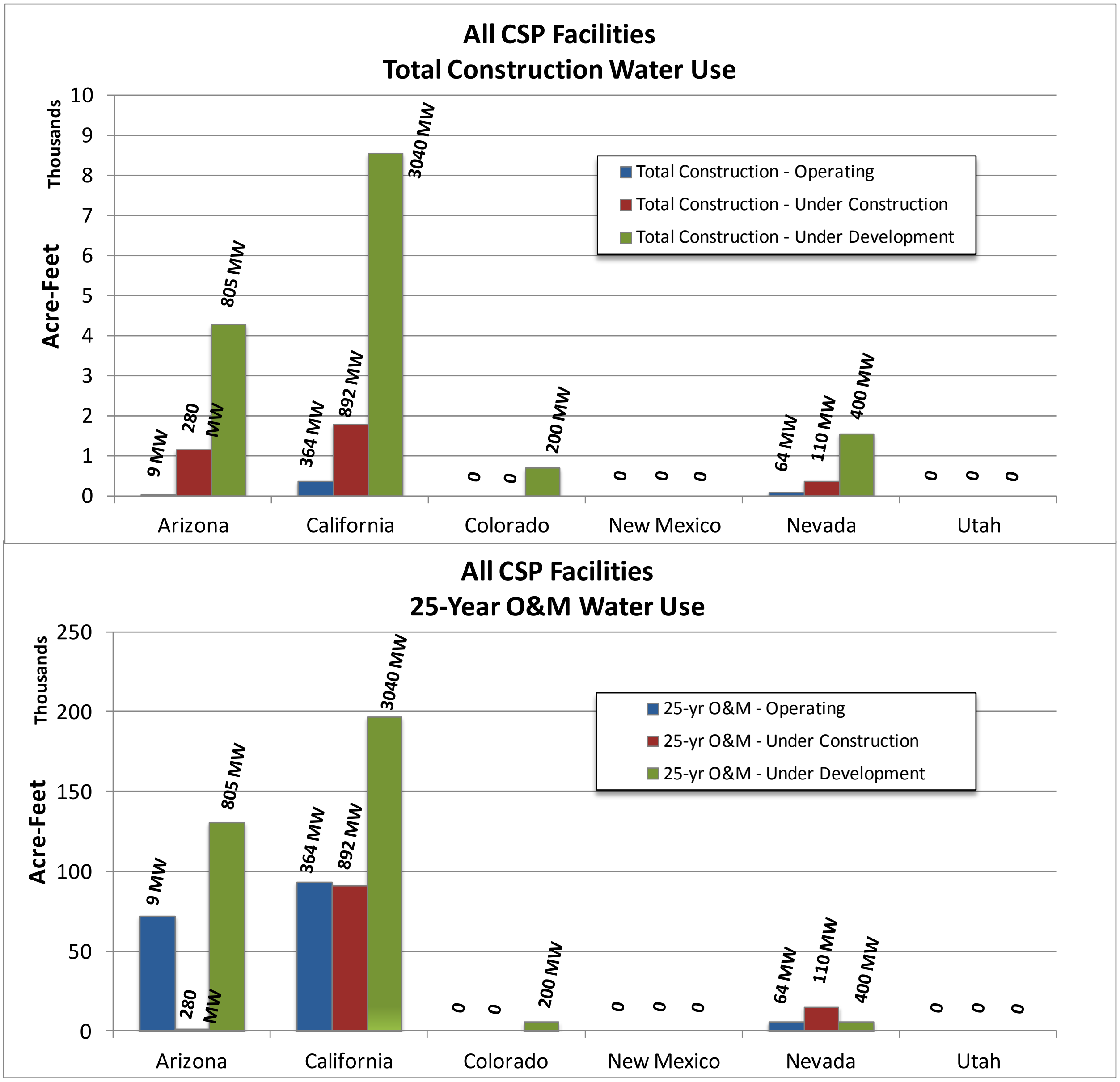


Figure 6. Construction and O&M water use estimates (consumption) for all CSP facilities in the six-state area. The total nameplate capacity represented by the different categories is also shown.

Results indicate that for operating CSP facilities, construction water use is 0.3% of the 25-year O&M water use, for facilities under construction, construction water use is 3% of the 25-year O&M water use, and for projects under development, O&M water use is 4% of the construction water use. An analysis of all CSP Projects in California in Figure 7 shows the range in construction water use and 25-year O&M water use, depending on the phase of development, using the *BLM PEIS Methodology*. The higher O&M water use for operating facilities then compared to facilities under development indicates the trend from wet cooled facilities to more dry cooled facilities in California. Using the *BLM PEIS Methodology* shows the construction water use at a greater fraction than the 25-year O&M water use for projects that are still being planned.

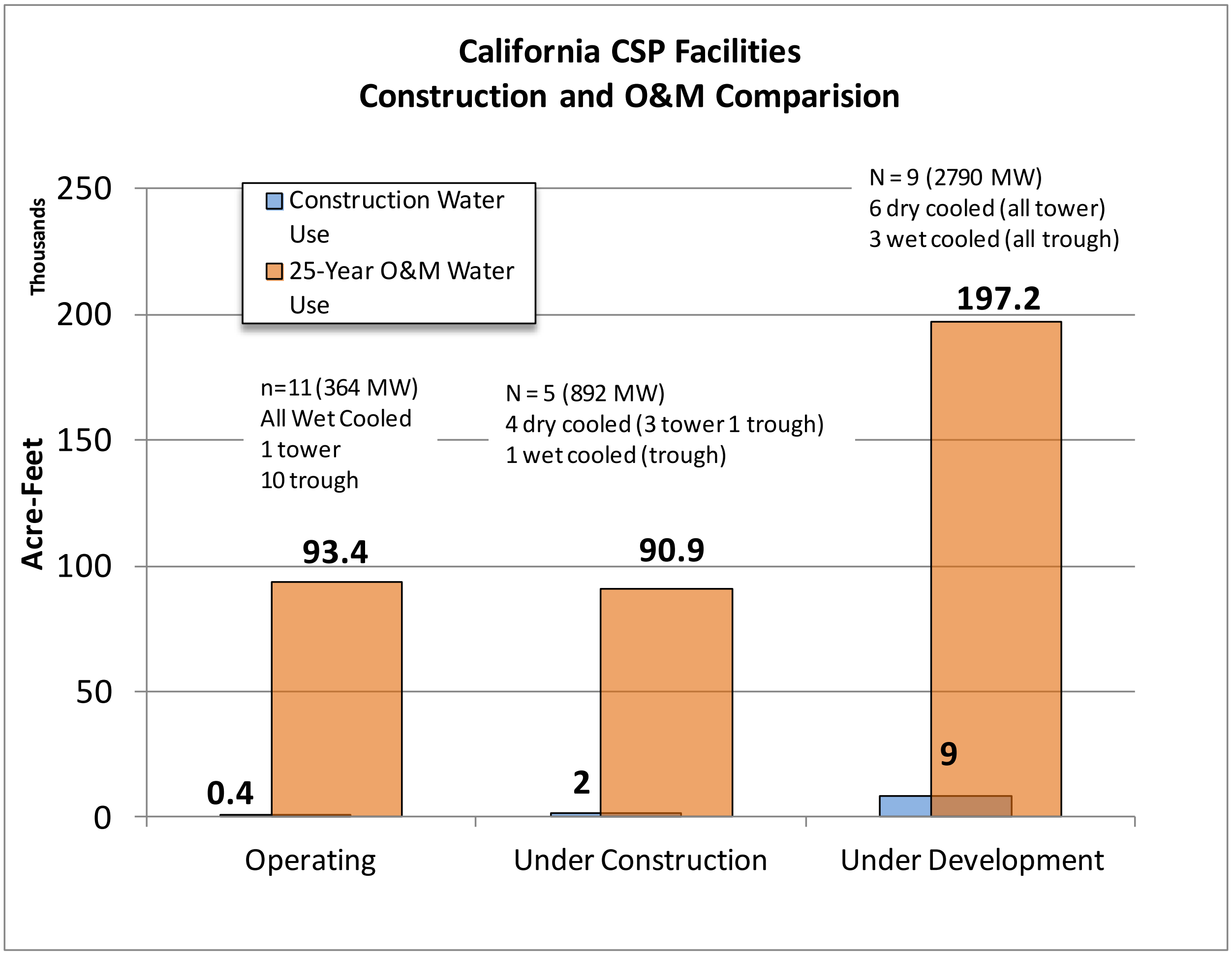
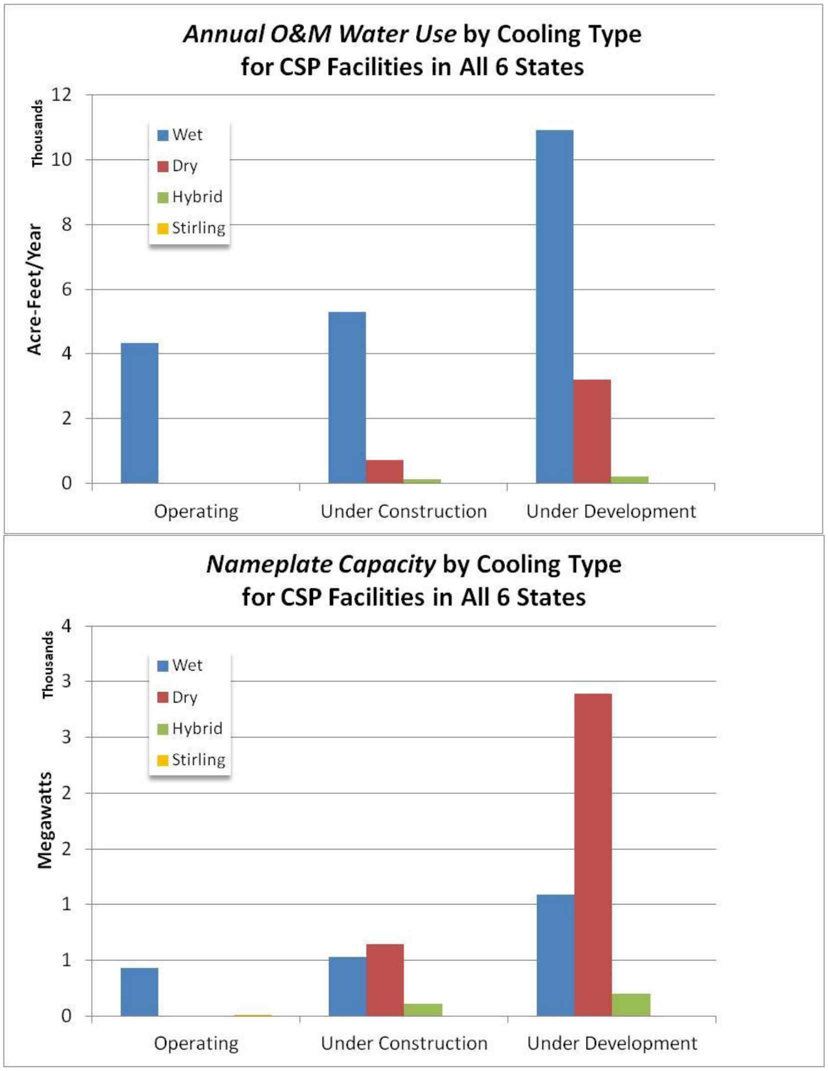


Figure 7. Construction and O&M water use estimates (consumption) for all CSP facilities in California. Details are provided on CSP type and cooling type, as well as nameplate capacity.

Sorting the data up by cooling type for O&M activities for all six states reveals wet cooled projects dominate the water usage in all classes, including Operating, Under Construction and Under Development, though the actual nameplate capacity of the CSP facilities is greater for dry cooling by a slight margin for facilities Under Construction and a large margin for facilities Under Development (Figure 8).



Annual O&M Water Use by Cooling Type for CSP Facilities in All 6 States

Nameplate Capacity by Cooling Type for CSP Facilities in All 6 States

Figure 8. Comparison between the water use for all CSP facilities in different stages to the nameplate capacity of those CSP facilities.

Overall, when making these comparisons between the different methodologies presented above, a few key observations can be made.

1) For Tower facilities, the *BLM PEIS Methodology* is lower than the Project Reported (estimated) for O&M water use. O&M for mirror washing in some cases exceeds the entire O&M estimates using the Macknick et al. (2011) consumption factors.
2) For Trough facilities, the *BLM PEIS Methodology* results in the highest estimate for O&M water use, followed by Burkhardt et al. (2011) “Operational” estimates, which appear the closest to the Project Reported estimates. Values reported using Macknick et al. (2011) consumption factors were the lowest for the facilities compared above.
3) For construction water use estimates, the *BLM PEIS Methodology* is lower than the Project Reported (estimated) water usage. The Burkhardt et al. (2011) estimates were compared for

trough facilities, though due to the absence of dust control water usage, these estimates were much lower.

To both validate and compare the water use of these PV and CSP facilities in terms of operational water use and consumption factors, the data was plotted on a chart by Macknick et al. (2012) to see how the *BLM PEIS Methodology* compares to other estimates for solar PV and CSP facility water use, as well as other fossil and renewable energy generating technologies (Figure 9). Results indicate that the mean value determined in this analysis was in the range of values for PV and CSP Trough and Tower facilities for wet and hybrid cooling. Dry cooling values for CSP Trough and CSP Tower technologies are higher by around a factor of 2, which may be explained by the methods utilized by the BLM to determine either the water used in dry cooling, as well as the mirror washing component (as a function of use and evaporation), which when calculated contributes almost half of the total estimated water consumption amount.

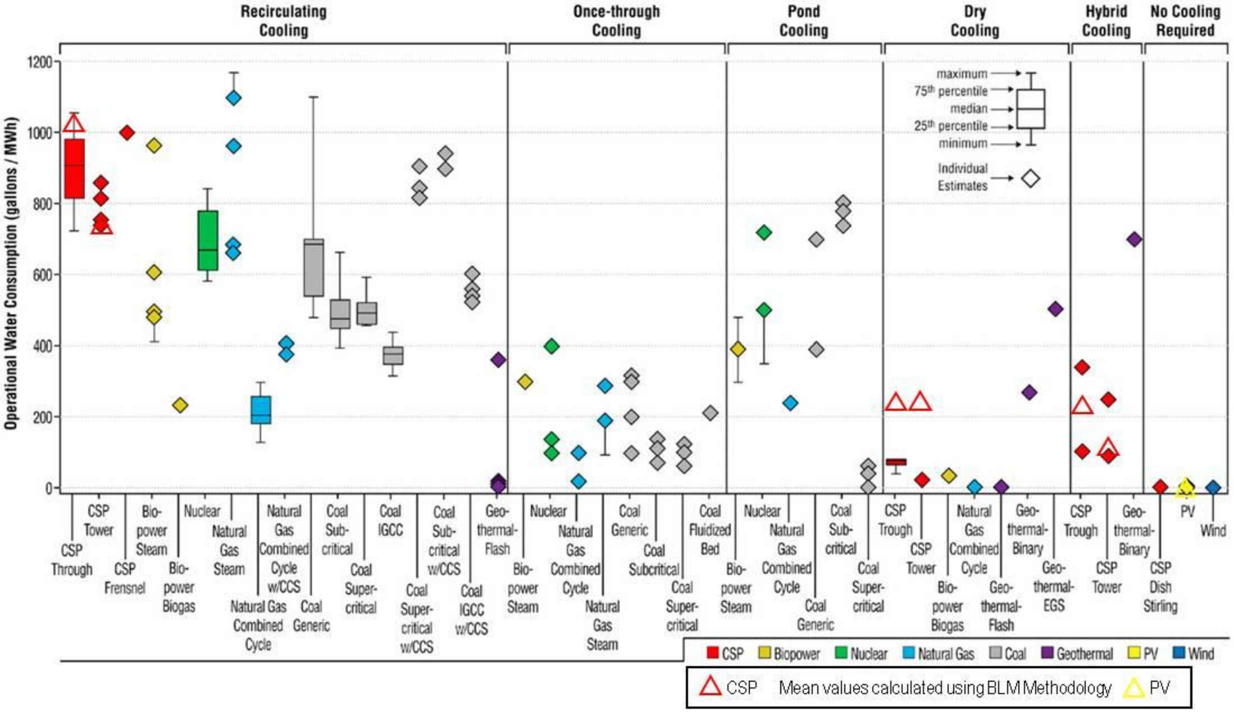


Figure 9. Operational water consumption factors from Macknick et al. (2012). Mean calculated PV and CSP operational water use values in gallons/MWh using the *BLM PEIS Methodology* are plotted as triangles.

2.6. Comparison of Water Use between Similarly Sized PV and CSP Facilities

How does the water usage compare across a similarly sized PV facility and CSP facility in terms of electricity produced? To make this comparison, we used a PV capacity factor of 20% for a facility in California, and compared PV and CSP facilities that are estimated to produce around 600 GWh/yr (Figure

10). All facilities are listed as either Under Construction or Under Development. Comparing these four facilities, the PV facility has higher annual construction water use of 298 gal/MWh when compared to O&M annual water usage of 9 gal/MWh. For the CSP technologies, the wet cooled Mojave Trough facility has the highest O&M water usage at 1359 gal/MWh and 65 gal/MWh for total construction water usage. The dry cooled Genesis Trough and Coyote Springs Tower facilities have somewhat similar annual O&M water usage, though with the Tower site, construction water usage is higher. The total O&M water usage for the two dry cooled facilities is only ~10% of the O&M water usage when compared to the wet cooled Mojave Trough facility.

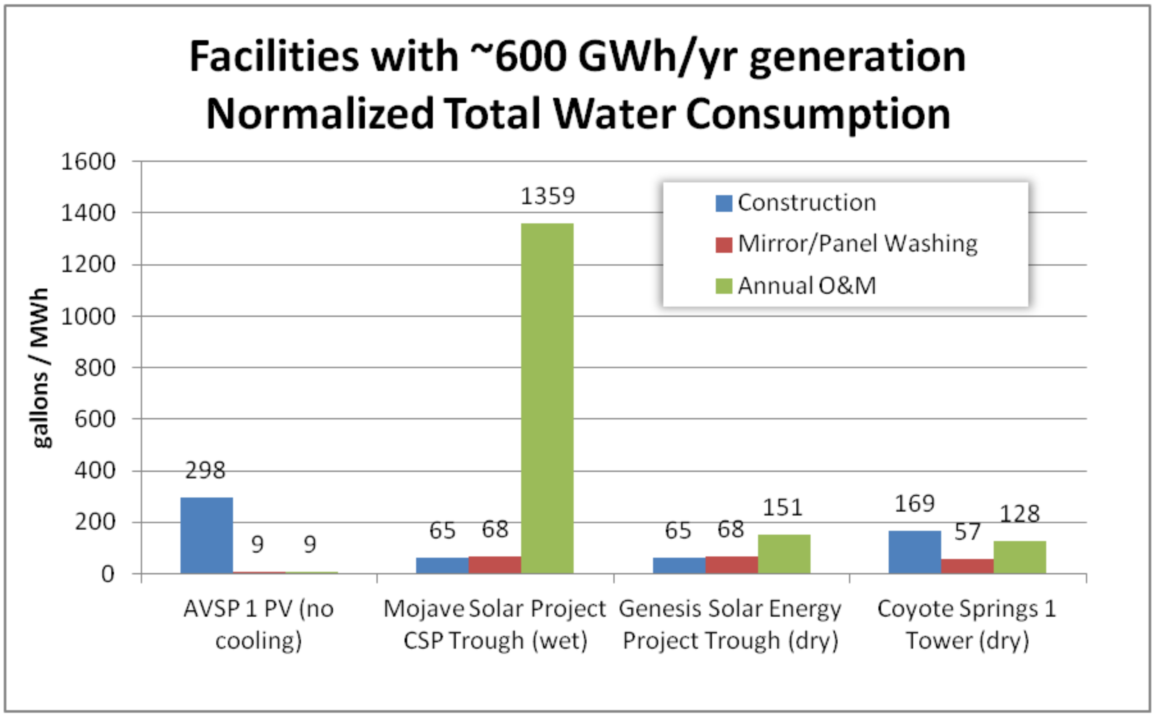


Figure 10. Comparison of 1 PV and 3 CSP facilities with different cooling options with approximately 600 GWh/year generation capacity. Results normalized to gallons/MWh to compare construction, mirror/panel washing and annual O&M water usage.

2.7. Estimates of Water Usage by 8-digit HUC

The facilities described above, including all CSP systems and all PV systems greater than 100MW were consolidated into each 8-digit HUC watershed to see the relative impact of PV and CSP system build out for each impacted watersheds.

Annual O&M Comparison

For PV facilities, the total annual O&M water use is shown in Figure 11. For CSP facilities, the total annual O&M water use is shown in Figure 12. The scale for annual watershed impacts is the same for both figures to show the comparison between annual PV impacts vs. annual CSP impacts for O&M water use.

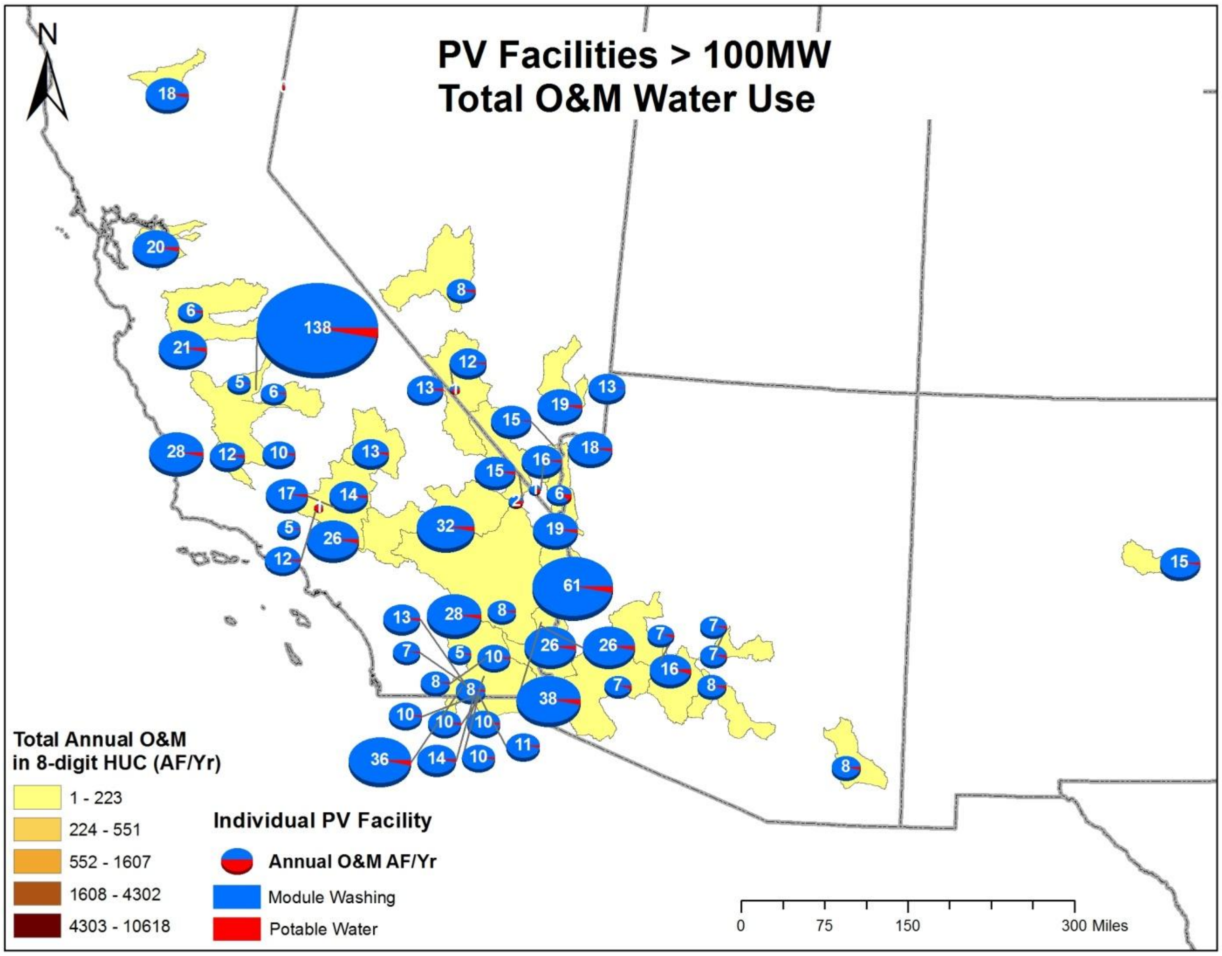


Figure 11. PV Facilities greater than 100 MW, with annual O&M water use showing the breakout in module washing and potable water needs. The watershed colors represent the cumulative impacts from each facility in those watersheds.

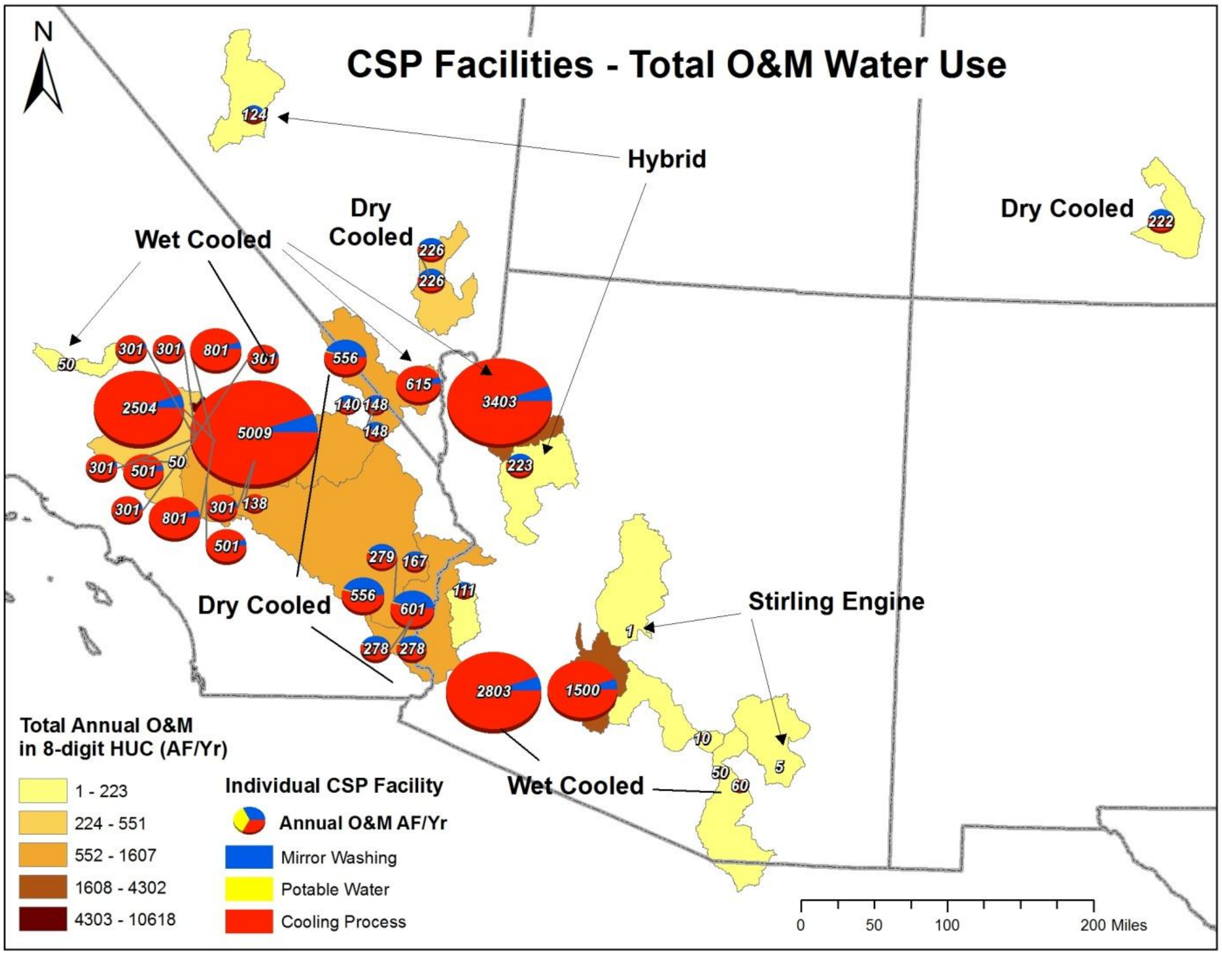


Figure 12. CSP facilities, with annual O&M water use showing the breakout in mirror washing, potable water and cooling process. Clusters of different cooling types are shown on the map. The watershed colors represent the cumulative impacts from each facility in those watersheds.

Results show that the O&M usage from PV is considerably lower than the O&M usage for CSP. Module washing dominates the PV O&M annual water usage, and for CSP, the cooling process dominates for all types of cooling, whether wet or dry, with the exception of the stirling engine technologies where there is no water used for cooling.

Construction and 25-Year O&M Comparison

Comparing both the construction water usage to the O&M water usage shown above in Figures 11 and 12 shows the relative impacts of construction vs. 25 years of O&M water usage (Figures 13 and 14).

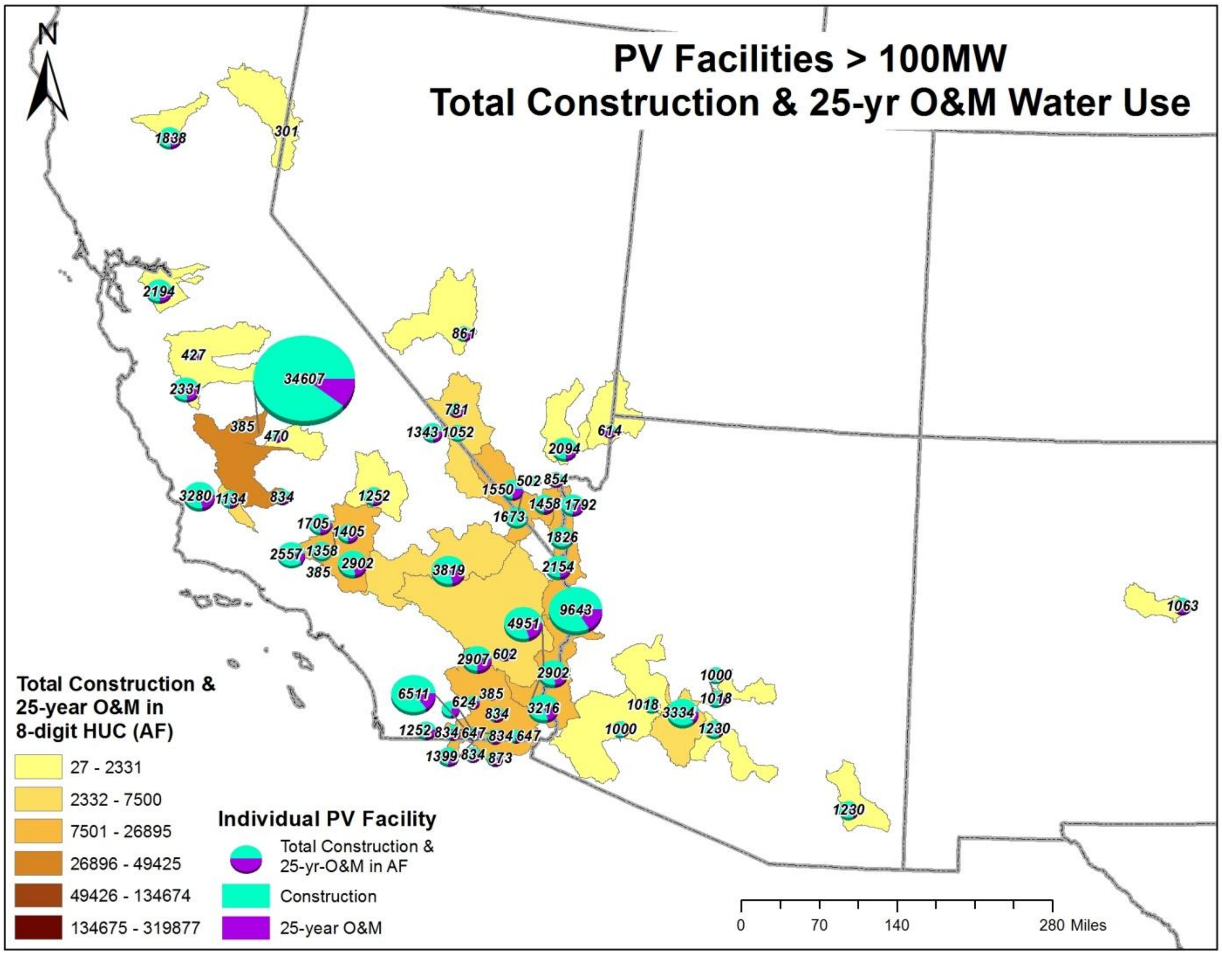


Figure 13. PV Facilities greater than 100 MW, with total construction and 25-year O&M water use in the pie charts. The watershed colors represent the cumulative impacts from each facility in those watersheds.

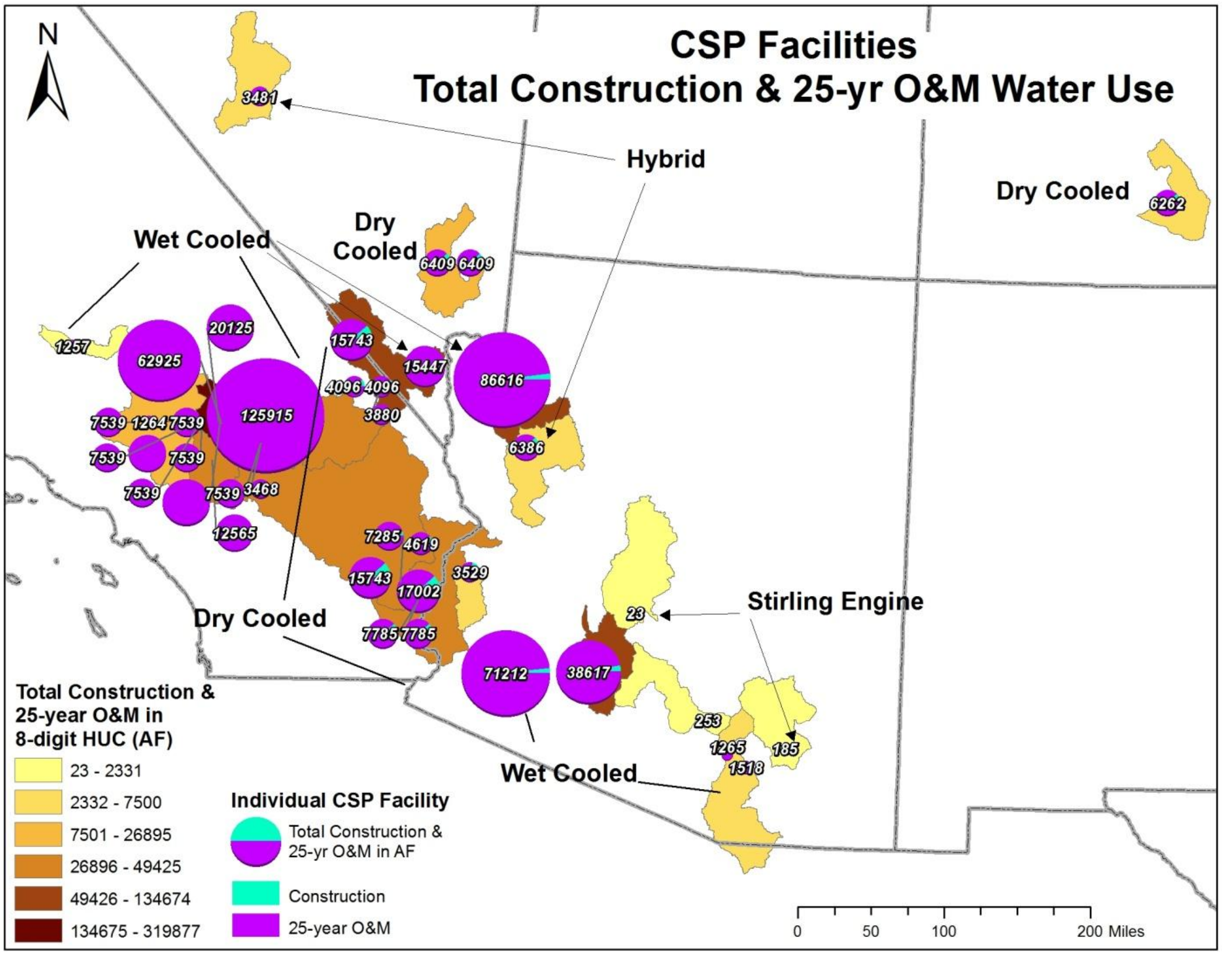


Figure 14. CSP Facilities, with total construction and 25-year O&M water use in the pie charts. The watershed colors represent the cumulative impacts from each facility in those watersheds.

Results indicate that for large PV systems, the construction water use is much greater than the O&M water use totaled over 25-years. For CSP systems, the reverse is true where the 25-year O&M water use is more often greater than the construction water use estimates.

Total PV and CSP Lifetime Impacts to Watershed

The water use estimates for both PV and CSP systems of all status types were combined to get an idea of the total impacts to each watershed, assuming all water consumed in facility construction and O&M activities comes from the underlying watershed (Figure 15).

Table 6. Sum of water use estimates by state and region

Location	Total Solar[i] 25-year Water Use (AF)	Total Solar[ii] Annual Average O&M (AF/yr)
Arizona	219,416	8,224
California	493,767	15,976

Colorado	6262	222
New Mexico	1063	15
Nevada	47,307	1,208
Utah	383	5
Entire Southwest	*768,198*	*25,651*

i – Construction and 25-year O&M water use for PV facilities greater than 100 MW and all CSP facilities that are operating, under construction and under development.
ii – O&M water use for PV facilities greater than 100 MW and all CSP facilities that are operating, under construction and under development over a 25-year period.

In Section 4, these total water use estimates are overlaid on maps of available water supplies to develop an idea where solar development will be problematic or should look to non-traditional water supplies.

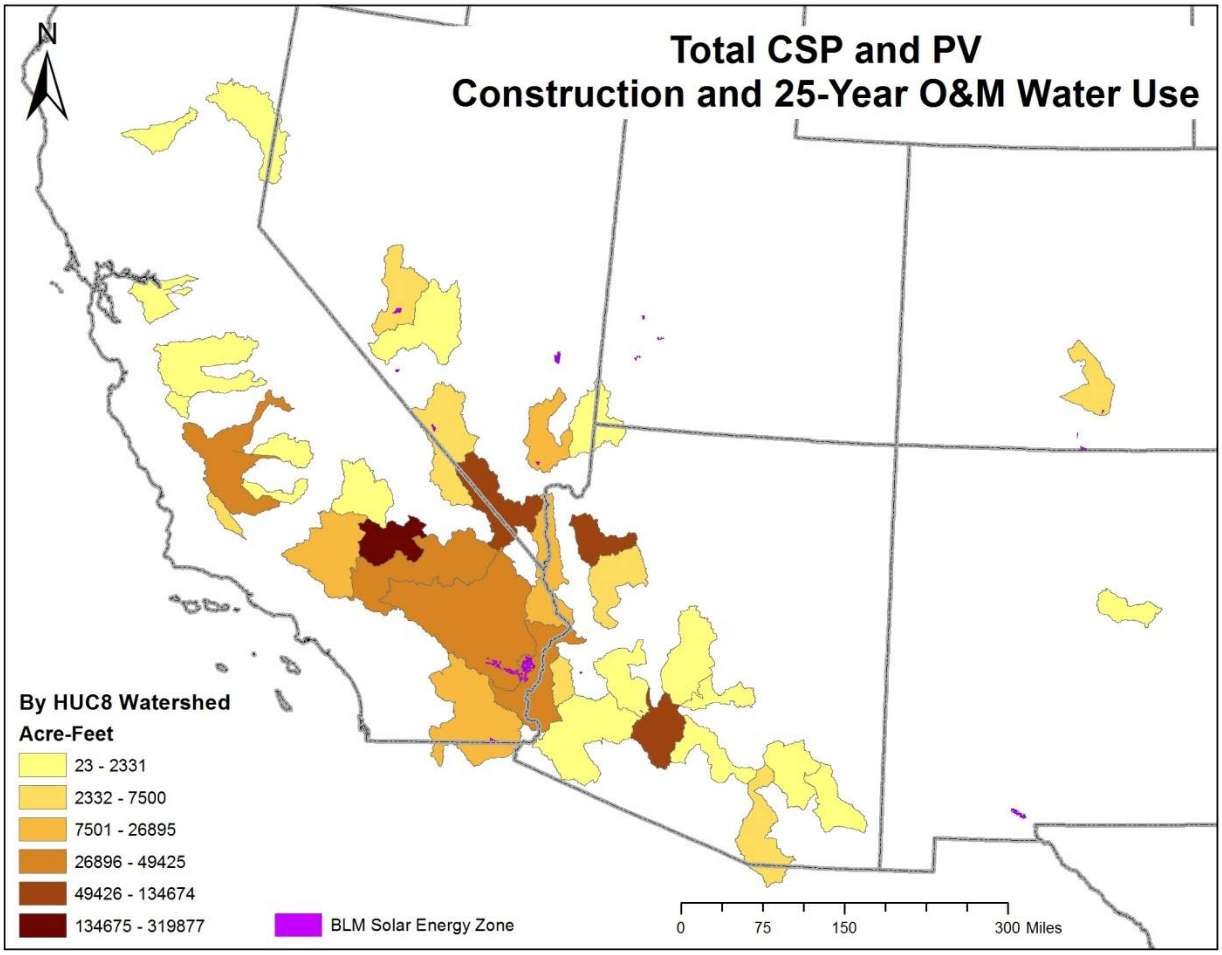


Figure 15 – CSP & PV Facilities, with total construction and 25-year O&M water use. The watershed colors represent the future cumulative impacts from each facility in those watersheds if all facilities used in this analysis are built.

2.8. Limitations

Estimates from the *BLM PEIS Methodology* are based on SEZs which are associated with very small areas. The figures above showing the SEZs in relationship to the watersheds gives an idea of the scale. Due to the use of SEZ data, the evaporation rates are extrapolated from the SEZ in that state, across the entire state. A more accurate estimate would be to obtain the evaporation rate for the specific site in question. Also, the land use requirements will be different for the different types of PV technologies, where some thin-film PV systems may need more area than a comparable sized crystalline PV facility. The *BLM PEIS Methodology* assumes one size for PV systems.

The *BLM PEIS Methodology* did not have estimates for concentrating PV, therefore estimates were obtained from a CPV manufacturer. However as the watershed analysis was limited to facilities greater than 100 MW, these sites were not included in the impacts analysis.

No information on non-peak water use as a factor of peak water use was available in the BLM data. A report for the Stateline project (BLM 2012b) has total non-peak estimates at 45% of peak; our estimate of 30% may underestimate the water needs in some locations.

As our impacts analysis is constrained to facilities over 100 MW to be consistent with the *BLM PEIS Methodology*, and ensure that no commercial systems (PV) are included in the analysis, the overall impacts to the watersheds are likely lower due to the combined water usage by facilities under 100MW. These smaller PV facilities likely utilize a municipal water source for washing. Other facilities less than 100 MW that are ground mounted likely have a construction water usage that is not captured in the impacts analysis.

As these large solar facilities are built, water use data will then be available to compare to these estimates and provide a more accurate look at the water use impacts of large solar projects in the southwestern U.S.

3. Water Availability and Cost

In efforts to determine where water could be a limiting factor in solar energy development, water availability, cost, and projected future demand are mapped for the 17-conterminous states in the western U.S. Specifically, water availability is mapped according to five unique sources including unappropriated surface water, unappropriated groundwater, appropriated surface/groundwater, municipal waste water, and brackish groundwater. Associated costs to acquire, convey and treat the water, as necessary, for each of the five sources are also estimated. To complete the picture, competition for the available water supply is projected over the next 20 years.

This data was originally compiled as part of a Department of Energy's Office of Electricity sponsored project supporting the Western Electricity Coordinating Council and the Electric Reliability Council of Texas to integrate water related issues into their long-range transmission planning.[5]

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[5] http://energy.sandia.gov/?page_id=1741

3.1. Methods

As described below, mapping water availability, cost and demand followed a three step process including raw data collection, translation of the data to a consistent reference system, and metric formulation.

Raw data were acquired from a variety of sources. Where available, data were collected directly from the western states. In collecting the data we worked directly with state water data experts to identify and at times gain access to the data. In most cases the data came from the state's water plan that was generally available from on-line sources (see Appendix 1 for a partial list of data sources). Efforts were made to vet the collected water data with the state experts to verify the fidelity of data collected and any data conversion/translation made to render the data in a consistent and comparable format. Federally reported data were used as necessary to fill in gaps, including information derived from the U.S. Geological Survey, Environmental Protection Agency, Energy Information Administration, U.S. Department of Agriculture and others.

This analysis makes use of multiple data sets from multiple sources reported at differing geographic resolutions (e.g., point, county, watershed, state). For purposes of this analysis, a consistent reference system is required. The 8-digit Hydrologic Unit Code (HUC) watershed classification (e.g., Seaber et al. 1987) is adopted, which resolves the 17 western states into 1208 unique hydrologic units. The 8-digit HUC is selected as it provides a physically meaningful unit relative to water supply/use and provides the highest level of detail that can be justified with the data consistently available across all 17 western states. For raw data reported in point-format, translation to the 8-digit HUC is achieved by simple aggregation/averaging. For raw data reported in polygonal-format, translation follows a simple population or areal weighting. In the case of water use data, the 1995 USGS water use reported at the 8-digit level (Solley et al. 1995) provides the needed spatial weighting function.

There are no definitive measures of water availability and cost that entirely span the full 17-state region. Rather, these metrics must be developed from the raw data collected from the states and federal agencies. The challenge is to formulate water availability and cost metrics that appropriately balance the underlying complexity of the system (e.g., physical hydrology, climate, use characteristics, technology and water management institutions) with the data that is consistently available across the entire western U.S. To assist in striking such a balance, water availability/cost metrics are formulated with the help of subject experts. Specifically, representatives from the Western Governors' Association, Western States Water Council, USGS, and individual state water management agencies assisted in defining appropriate and informative water metrics (in total the team included 11 participants plus the author team). These metrics were developed and vetted over a two month period during 6 webinars lasting roughly 90 minutes each. The resulting metrics are described below.

Water Availability Metrics

Unappropriated Surface Water: States exercise full authority in matters pertaining to off-stream water use. In the western states water is managed according to the doctrine of prior appropriation, which defines a system of priority where the first to make beneficial use of water has the first right to it in times of drought. Access to this water requires only a permit or water right issued by the state's water management agency. However, any new water development is allocated the most junior priority in the basin, thus delivery in times of drought may be limited. Whether water is available for new development depends on characteristics of the physical water supply, the water rights structure in relation to supply, and related instate compacts and international treaties. Additionally, navigational or environmental regulation may further limit allocation or timing of deliveries. Particularly in arid regions the states have estimated how much surface water is available for new development. Although the states have different terms for such water, we refer to it as unappropriated surface water.

For purposes of this analysis, state estimated unappropriated surface water values are adopted where available, including Arizona, Colorado, Nevada, New Mexico, Oklahoma, Oregon, Texas, Utah, and Wyoming. Estimates of available unappropriated surface water are based on years with normal stream flow. Although availabilities based on drought flows would yield a more dependable estimate for new development, such estimates were available only for a single state, Texas. For states that have not estimated unappropriated surface water availability, efforts are made to first identify basins closed to new appropriation, in such cases available unappropriated water is set equal to zero. In the remaining open basins, streams tend to lack regulation by interstate compacts and flows tend to be large with respect to water use. Given this lack of stringent control on water use, environmental concerns are the most likely factor to constrain new water development. A widely used environmental standard in the U.S. (Reiser et al. 1989) is based on studies by Tennant (1976) which found streams maintain excellent to good ecosystem function when stream flows are maintained at levels of ≥60-30% of the annual average. For this study we adopt a conservative threshold of 50% to define unappropriated surface water. Thus for basins where estimates are not available directly from the states, unappropriated surface water is calculated as:

$$Q_{usw}^{j} = 0.5 * \left(Q_{avg}^{j} + C^{j}\right) - C^{j}$$

where *j* designates the watershed, Q_{avg} is the long term annual average gauged stream flow*, C* is the total consumptive use of water upstream of the gauging point. Annual average stream flow data are taken from the National Hydrography Dataset (NHDPlus 2005) while consumptive water use data are taken directly from individual state estimates.

Unappropriated Groundwater: States exercise full authority over the allocation of groundwater resources. Determining the availability of groundwater for future development is complicated by numerous factors including the manner with which groundwater is managed (e.g., strict prior appropriation, right of capture); the physical hydrology of the basin; degree of conjunctive management between surface and groundwater resources; allowable depletions, and a variety of other issues. Except in very limited cases, the states have not broadly estimated and published data on the availability of unappropriated groundwater.

Given the aforementioned complexity and relative lack of supporting data, a simple water balance approach is adopted to identify potable groundwater that is potentially available for development. That is, unappropriated groundwater is set equal to the difference between annual average recharge and annual groundwater pumping. Recharge rates are taken from U.S. Geological Survey (2003), which are derived from stream baseflow statistics, while pumping rates are taken from state data where available or from U.S. Geological Survey (Kenny et al. 2009) otherwise.

To account for unique groundwater management and/or aquifer characteristics, further restrictions on unappropriated groundwater availability are introduced. Specifically, availability is set to zero in watersheds located within state defined groundwater protection zones (data acquired directly from each state). Groundwater availability is likewise set to zero in watersheds realizing significant groundwater depletions (historical groundwater declines exceeding 40 ft. as given by Reilly and others [2008]). Finally, groundwater availability is set equal to zero in any watershed that 10% or less of its land area is underlain by a principle aquifer (Reilly et al. 2008).

Appropriated Water: This source attempts to quantify water that could be made available for new development by abandonment and transfer of the water right from its prior use. Such transfers have traditionally involved sales of water rights off irrigated farm land to urban uses. The potential for such transfers is estimated based on the irrigated acreage in a given watershed that is devoted to low value agricultural production; specifically, irrigated hay and alfalfa. Data (irrigated acreage and water volume applied) are taken from the U.S. Department of Agriculture's Agricultural Census (USDA 2007). There is often resistance to large areas of irrigated agriculture being abandoned. As such, land abandonment is limited to 5% of the total irrigated acreage in the watershed. This limit is based on the state projected average decline in irrigation across the western U.S.

For watersheds experiencing significant groundwater depletions (see unappropriated groundwater metric above) the available appropriated water is reduced by 50%. This is to account for the fact that some portion of future water rights abandonment is likely to be used to offset the groundwater depletion (Brown 1999).

Municipal Waste Water: Non-fresh water supplies offer important opportunities for new development. Municipal waste water is rapidly being considered as an alternative source of water for new development, particularly in arid regions. Municipal waste water discharge data is relatively consistently available throughout the U.S. The Environmental Protection Agency publishes a pair of databases (Permit Compliance System [EPA 2011b], and Clean Watershed Needs Survey [EPA 2008]) that provide information on the location, discharge, and level of treatment for most waste water treatment plants in the U.S. Additionally, the U.S. Geological Survey (Kenny et al. 2009) publishes municipal waste water discharge values aggregated at the county level. These three sources of information are combined to provide a comprehensive view of current waste water discharge across the West. Lastly, the projected growth in municipal waste water discharge to 2030 is estimated (see future Water Demand section below) and added to the current discharge rates.

However, not all of this discharge is available for future use. A considerable fraction of waste water discharge is currently re-used by industry, agriculture, and thermoelectric generation. Re-use estimates are determined both from the U.S. Geological Survey (Kenny et al. 2009) data as well as the Environmental Protection Agency databases (as they record the point of discharge, e.g., stream, agriculture, power plant and in some cases are designated as discharging to 'reuse'). These re-use estimates are subtracted from the projected discharge values.

In western states the availability of municipal waste water must consider return flow credits. Those municipalities that discharge to perennial streams receive return flow credits for treated waste water. This water is not available for new development as it is already being put to use downstream. Unfortunately, there are no comprehensive data on waste water return flow credits. In efforts to identify plants that are likely credited for their return flows, those plants that directly discharge to a perennial stream are identified (point of discharge is identified in the databases noted above). These plants are excluded as a source of available municipal waste water.

Shallow Brackish Groundwater: For this analysis brackish water availability is limited to resources no deeper than 2500 feet and salinities below 10,000 total dissolved solids (TDS). Deeper, more concentrated resources would generally be very expensive to exploit.

Estimates of brackish groundwater resources across the western U.S. are very spotty. To cover this entire area requires the use of multiple sources of information. The best quality data are state estimated volumes of brackish groundwater that are potentially developable; however, this data is only available for Texas (LBG-Guyton Associates 2003), New Mexico (Huff 2004), and Arizona (McGavock 2009). States limit exploitation of the resource by applying some type of allowable depletion rule. In this case it is assumed that only 25% of the resource can be depleted over a 100 year period of time (annual available water is determined by multiplying estimated total volume of brackish water by 0.0025).

The next best source of data is reported use of brackish groundwater as published by the U.S. Geological Survey (Kenny et al. 2009). This does not provide a direct measure of available water, simply an indication that brackish water of developable quality is present. Conservatively we assume that double the existing use could be developed up to a maximum limit of $8.4X10^{-2}$ AF/yr. Also assumed is that the minimum quantity available is $8.4X10^{-3}$AF/yr.

Finally, if a watershed has no brackish water volume estimate or brackish water use then the presence of brackish groundwater wells is used. The U.S. Geological Survey maintains the National Water Information System (NWIS) database which contains both historical and real-time data of groundwater well depth and quality (USGS 2011). Where at least one well exists, brackish water availability is set to $8.4X10^{-3}$AF/yr. To avoid brackish water that is in communication with potable stream flow, availability is set to zero when the average depth to brackish water is less than 50 ft. and the salinity is less than 3000 TDS.

Water Cost Metrics

Each of the five sources of water carry a very different cost associated with utilizing that particular supply. The interest here is to establish a consistent and comparable measure of cost to deliver water of potable quality to the point of use. As with water availability, costs are resolved at the 8-digit HUC level. Considered are both capital and operating and maintenance (O&M) costs. Capital costs capture the purchase of water rights as well as the construction of groundwater wells, conveyance pipelines, and water treatment facilities, as necessary. All capital costs are amortized over a 30-yr horizon and assume a discount rate of 6%. O&M costs include expendables (e.g., chemicals, membranes), labor, waste disposal as well as the energy to lift, move and treat the water. Below, specifics unique to each source are discussed.

Unappropriated Surface Water: No costs are assigned to unappropriated surface water. It is recognized that there are costs associated with constructing intake structures and permitting. Such costs are not considered in part because of the wide range of variability across use types and location. More importantly, similar intake and permitting costs will be realized with all five sources of water, thus estimating these uncertain costs are of little value to this effort.

Unappropriated Groundwater: Estimated costs consider both capital and O&M costs to lift water for use. Capital costs for drilling are estimated along with electricity to lift water following the approach outlined in Watson and others (2003). Depth to groundwater is taken from U.S. Geological Survey well log data (USGS 2011) and averaged at the 8-digit HUC level.

Appropriated Surface Water: Water rights transfer costs are based on historic data collected by the *Water Strategist* and its predecessor the *Water Intelligence Monthly* (Water Strategist 2012). Costs are estimated by state because of the limited availability of data. Only transactions involving permanent transfers from agriculture to urban/industrial use are considered. Recorded transfers are averaged by year and by state and the average of the last 5 years used for purposes of this study. No efforts are made to project how costs may vary in time given the wide range of factors and associated uncertainty that plays into the water transfers market.

Municipal Waste Water: Estimated costs consider expenses to lease the waste water from the municipality, convey the water to the new point of use, and to treat the waste water. Fees charged to lease treated waste water from the municipality were estimated based on the initial work of the Electric Power Research Institute (EPRI 2008). Values reported in the EPRI report were verified and updated as necessary based on a review of fees published on line. As no geospatial or plant related trends were noted in the pricing an average of the reported fees was adopted for this study, which was calculated at $1.21 per thousand gallons.

Conveyance of treated waste water from the treatment plant to the point of use is a potentially important cost. Considered are both capital construction costs for a pipeline and O&M costs principally related to electricity for pumping. Associated costs calculations are consistent with Watson and others (2003). The key factor in this analysis is the distance between the treatment plant and point of use. Distance values are calculated as a function of the land use density around the existing treatment plant. Land use densities were calculated within a 5 mile buffer around all existing treatment plants with conveyance distances simply distributed according to a rank order of land density with low values given a conveyance distance of 1 mile to the highest land use density given a distance of 5 miles.

It is assumed that all waste water must be treated to advanced standards before it can be re-used. This conservative assumption was adopted considering both realized improvements in downstream operations (e.g., increased cycles of use, reduced scaling, improved feed quality) and the current trend of regulation toward requiring advanced treatment (EPRI 2008). Plants operating at primary or secondary treatment levels (EPA 2008; 2011a) are assumed to be upgraded to advanced standards. Capital construction costs are based on the analysis of Woods et al. (2012), which scale according to treatment plant throughput and original level of treatment. Associated O&M costs consider expenses for electricity, chemicals and labor.

Shallow Brackish Groundwater: Estimated costs consider both capital and O&M costs to capture and treat the brackish groundwater. Cost calculations follow standards outlined in the Desalting Handbook for Planners (Watson et al. 2003). Capital costs include expenses to drill and complete the necessary groundwater wells and construct a treatment plant utilizing reverse osmosis. Number of wells and treatment plant capital costs are based on the treated volume of water, which is assumed to be 4.2X10^{-2}AF/yr. Other key design parameters include the depth of the brackish water and TDS. These data averaged at the 8-digit HUC level, were estimated from the U.S. Geological Survey brackish groundwater well logs (USGS 2011). O&M costs capture expenses for labor, electricity, membranes and brine disposal.

Water Demand

There are a number of water use sectors competing for the available water supplies mapped above. As with water availability we worked closely with state water managers to characterize projected water demand across the western U.S. Acquired data has largely come from the state's individual water plans and online databases (see Appendix 1). Water demands are distinguished according to current verses projected future demands; withdrawal verses consumptive use; and, the source water (e.g., surface water, groundwater, waste water, saline/brackish water). Demands are also distinguished by use sector; specifically, municipal/industrial, thermoelectric, and agriculture.

Water demand projections vary by state in terms of spatial resolution, target dates, and categories of growth. All projected demands are mapped to an 8-digit HUC level following a strategy similar to that adopted and discussed for water availability. Projections were also uniformly adjusted to the year 2030. This was achieved through simple linear extrapolation between current use estimates and that projected at target dates beyond 2030. Although data were collected for all reported growth scenarios (e.g., high, medium and low), the medium growth projections are reported here.

3.2. Water Availability and Cost Results

Water Availability

Water availability is mapped for the five unique sources of water for the 17 conterminous western states at the 8-digit HUC level as shown in Figure 16. Water availability for all five sources is mapped using a consistent but non-linear scale. Watersheds marked in white designate basins with no availability for that source of water (or insufficient information to suggest a reliable supply in the case of brackish groundwater). A quick review of all five maps clearly reveals significant variability across the five sources of water as well as watershed-to-watershed variability within each source of water. The expressed variability is a function of the physical hydrology, water use characteristics, and water management practices unique to each watershed. Another notable feature is the lack of available water for any of the three potable water sources in the state of California. This reflects the fact that California requires new thermoelectric power plants to fully exhaust alternative water sources before considering freshwater (California Water Code, Section 13552)[6].

Availability of unappropriated surface water (Figure 16a), that water that only requires a permit from the state's water management agency to develop, is limited. No unappropriated surface water is available in Arizona, New Mexico, Nevada, California or Utah. Limited availability is noted for Oregon, Wyoming, Montana, Idaho, Colorado, Kansas and Texas. Broader availability is noted for North Dakota, South Dakota, Nebraska, and Oklahoma. However, where unappropriated surface water is available, appropriable volumes tend to be large relative to other sources.

Unappropriated groundwater (Figure 16b) is also of limited availability in the West. All states, except California, have some limited availability of unappropriated groundwater, while the best availability is noted for Oregon, Wyoming and the western slope of Colorado.

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[6] http://www.leginfo.ca.gov/cgi-bin/displaycode?section=wat&group=13001-14000&file=13550-13557

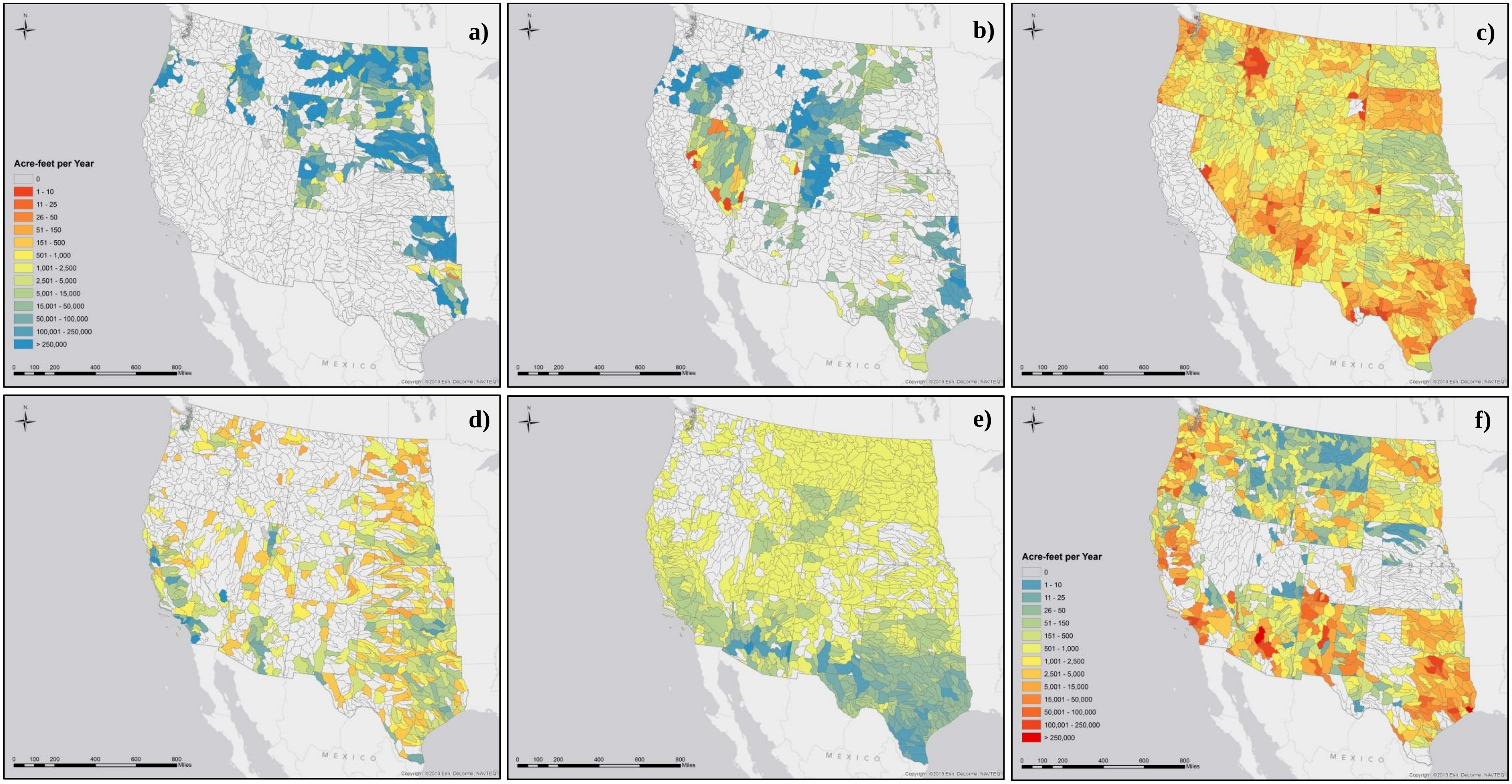

Figure 16. Water availability and future demand. Mapped are water availability metrics for a) unappropriated surface water, b) unappropriated groundwater, c) appropriated water, d) municipal waste water, e) brackish groundwater, and f) projected increase in consumptive water use between 2010 and 2030. All metrics are mapped at the 8-digit HUC level. All are mapped to a consistent non-linear color scale; however the color scheme is reversed between availability and demand (e.g., hot colors indicate limited availability and high demand).

Availability of appropriated water, both surface and groundwater that must be transferred from another use, is consistently distributed throughout the west (Figure 16c). Quantities likely to be transferred are relatively small, generally less than 2500 AF/yr. The greatest availability corresponds to regions with heavy irrigated agriculture including, southern Arizona, central California, eastern Colorado, panhandle of Texas, central Washington, and the Snake River basin in Idaho.

Availability of municipal waste water is sporadically distributed across the west (Figure 16d). Availability is most uniform in the far eastern portion of the study area where the density of communities is the greatest. The highest availabilities are associated with large metropolitan areas such as along the southern coast of California and near Tucson and Phoenix in Arizona.

Brackish groundwater is available throughout much of the west except in the far Northwest (Figure 16e). The highest availabilities are noted in Arizona, New Mexico and Texas, where detailed brackish groundwater studies have been conducted. Thus mapped availability is more an indication of what we know and currently use than an indication of the actual resource in the ground.

Future Water Demand

Projected future demands for water (consumptive use) are mapped in Figure 16f. Mapped are new demands projected between 2010 and 2030. Excluded from these projected demands is water for new thermoelectric development as that component will be developed through interaction with the WECC planning process. Demands are mapped at the same scale as water availability (Figures 16a-e) but with the color scale reversed to distinguish high demands with hot colors. A noteworthy aspect of the map is the large regions with zero to negative projected future demands (white areas on map). These are regions where the state projects some level of abandonment of irrigation combined with limited rural population growth. While the states project little growth (or declines) in irrigated agriculture, healthy increases in the municipal and industrial sectors are expected. It follows that the largest growth is clustered around metropolitan areas; particularly, along the West Coast (north and south), Tucson/Phoenix, Dallas/Fort Worth, Houston, Denver, Salt Lake City, Las Vegas and Albuquerque.

Water Cost

Water costs associated with all sources of water except unappropriated surface water are mapped in Figure 17. In order to map all four costs comparably, a non-linear color scale was necessitated to capture the broad range in values. Note that costs were not calculated for watersheds where a particular supply of water was unavailable (watersheds mapped white).

Each water supply shows some degree of watershed-to-watershed variability. This variability is masked to some extent for the brackish and wastewater maps by the large bin sizes necessitated for the scale. Variability in cost for unappropriated groundwater largely corresponds with the average depth to groundwater. Appropriated water transfers are seen to be more costly in the Southwest where water supplies are most limited. Municipal waste water costs tend to increase as the size of the waste water treatment plant decreases and the level of treatment increases. Brackish water costs tend to increase as depth and TDS increases.

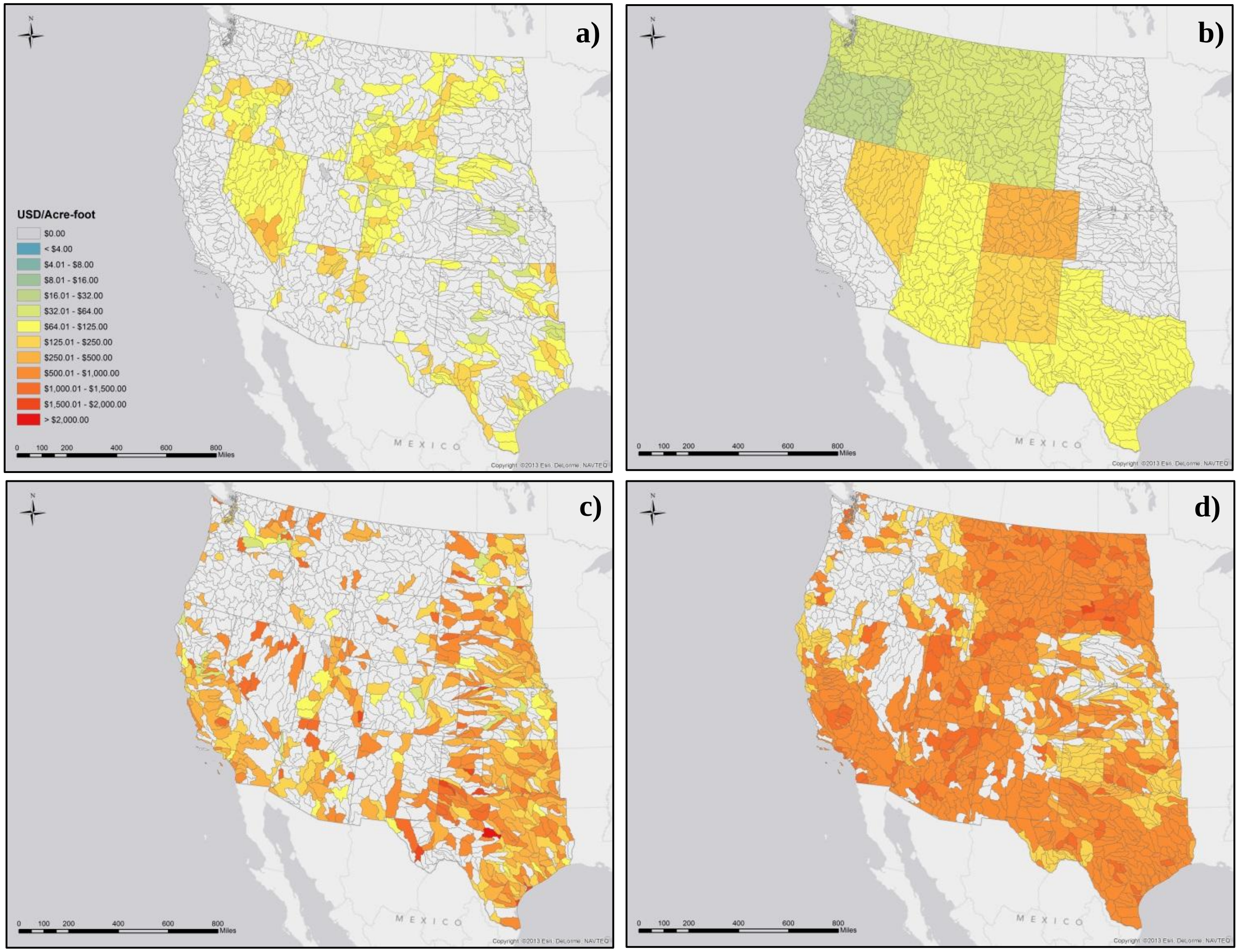

Figure 17. Water cost. Mapped are water cost metrics for a) unappropriated groundwater, b) appropriated water, c) municipal waste water, and d) brackish groundwater. All metrics are mapped at the 8-digit HUC level. All are mapped to a consistent non-linear color scale.

The most important feature of these maps is the significant variability across sources, particularly between fresh and non-fresh. Average costs for unappropriated groundwater run $107/AF while appropriated water is estimated at $21/AF. Alternatively non-fresh supplies are considerably more expensive with municipal waste water running $400/AF and brackish water $704/AF. Historically, development has largely relied on inexpensive unappropriated water or transfers of appropriated water. The cost of water is likely to play a much more important role in planning and design of future development.

3.3. Decision Support System

To help visualize and analyze the breadth of water and energy data collected through the project a web-served, interactive decision support system (DSS) has been developed. The DSS is created in ArcView Geographic Information System. Data are imported as unique data layers in point or polygonal format. Broad data types include individual power plant attributes (e.g., type, capacity, water source, water use), water demand (current/future, source, withdrawal/consumption, sector), water supply (gauged flows, groundwater recharge, reservoir storage), institutional controls (e.g., unappropriated water, closed basins, compact deliveries), and planning metrics (water availability, cost, environmental). All data are rendered in consistent units for the 17 conterminous western United States. Data can be viewed over a range of different reference systems including 8-digit HUC, county, state, and interconnection. Data can be viewed, overlaid, and displayed in bar and pie charts.

The DSS is implemented within the framework of the Water Use Data Exchange, which is a collaborative effort between the WSWC, the Western States Federal Agency Support Team (WestFAST), the WGA, and the Department of Energy Laboratories. The purpose of the Water Use Data Exchange is to better enable the western states to share water use, water allocation, and water planning data with one another and with the Federal Government. It also seeks to improve the sharing of Federal data that supports state water planning efforts.

The exchange relies upon a web-services-based approach allowing each of the states to maintain their current data systems as they currently exist, with their data mapped to a standard format. Using automated processes, these data are published over the web using eXtensible Markup Language (XML) and are discoverable via a common catalog that is maintained at the WSWC.

To make this data easily accessible to the solar industry links to key solar databases will be established. Specific, linkages include the National Renewable Energy Laboratory's Solar Prospector and the Boise State Solar Siting Tool.

4. Solar Water Demand and Water Availability

Now, projected water demand for solar development is compared to water availability for the six southwestern states (Figure 18). To accomplish this, total CSP and PV construction and O&M water use (Figure 15) are mapped onto the five available water supplies (Figure 16). In these figures water availability is denoted by the color of the watershed (cool colors are associated with high water availability, white designates no availability), while projected solar water demand is designated by the thickness of the line bordering the watershed (thick notes a high demand over the next 35 years). Thick lines around white or hot colored watersheds would indicate a situation where water for projected solar development exceeds the available water supply.

Inspection of Figure 18 reveals an apparent lack of unappropriated water in watersheds with likely solar development. Recall that California has policies that strongly discourage use of potable water supplies in support of new energy development. Unappropriated groundwater is only available in 7 Nevada watersheds and 3 Arizona watersheds (Figure 18b). In contrast appropriated water (Figure 18c, where the water right is transferred from an existing use to a new use) is available in every solar development watershed outside of the state of California. As expected, this analysis suggests very limited availability of traditional fresh-water supplies for any new development in the Southwestern U.S.

A different picture emerges when non-fresh supplies of water are considered. Review of available waste water indicates a viable supply in all but a handful of rural watersheds (Figure 18d). Brackish groundwater is even more widespread with all but 5 watersheds with solar development having some availability (Figure 18e). While the availability of waste water and brackish water matches well with projected solar development, it will come at a higher price than historically paid by the energy sector.

Review of Figure 18f indicates a mix of solar development in rural verses urban watersheds. Development in California and Arizona is roughly equally distributed between urban and rural, while the other four states are dominated by rural development. This is important as solar development in urban watersheds will be competing against other sectors for limited water supplies.

In reviewing all the watersheds with projected solar development, nine in California and one in New Mexico have only one available source of water indicated. Fortunately only two of the watersheds, in California, are also projecting significant competition from other water use sectors. These ten watersheds represent the most problematic in terms of available water supply for development. It should be realized that this analysis is not intended to project water availability associated with any particular project; rather, it strives to identify those basins where water is likely to be more difficult to permit and or expensive to obtain.

Also of interest is the manner with which the BLM SEZ's map to water availability. Because of the relative small size of the SEZ's, water availability is projected in the form of a table (Table 7) rather than a map. The water availability values reported are the 8-digit HUC values in which the SEZ is situated. Review of the data suggests limited availability of unappropriated water, with only six SEZ's with available unappropriated groundwater. Also of note is the limited availability of municipal waste water for any of the SEZ's. A relatively good alternative is brackish groundwater which is available in 9 of the 17 SEZ's. The best source appears to be appropriated water in which 15 SEZs have availability of 100 AF/yr or more.

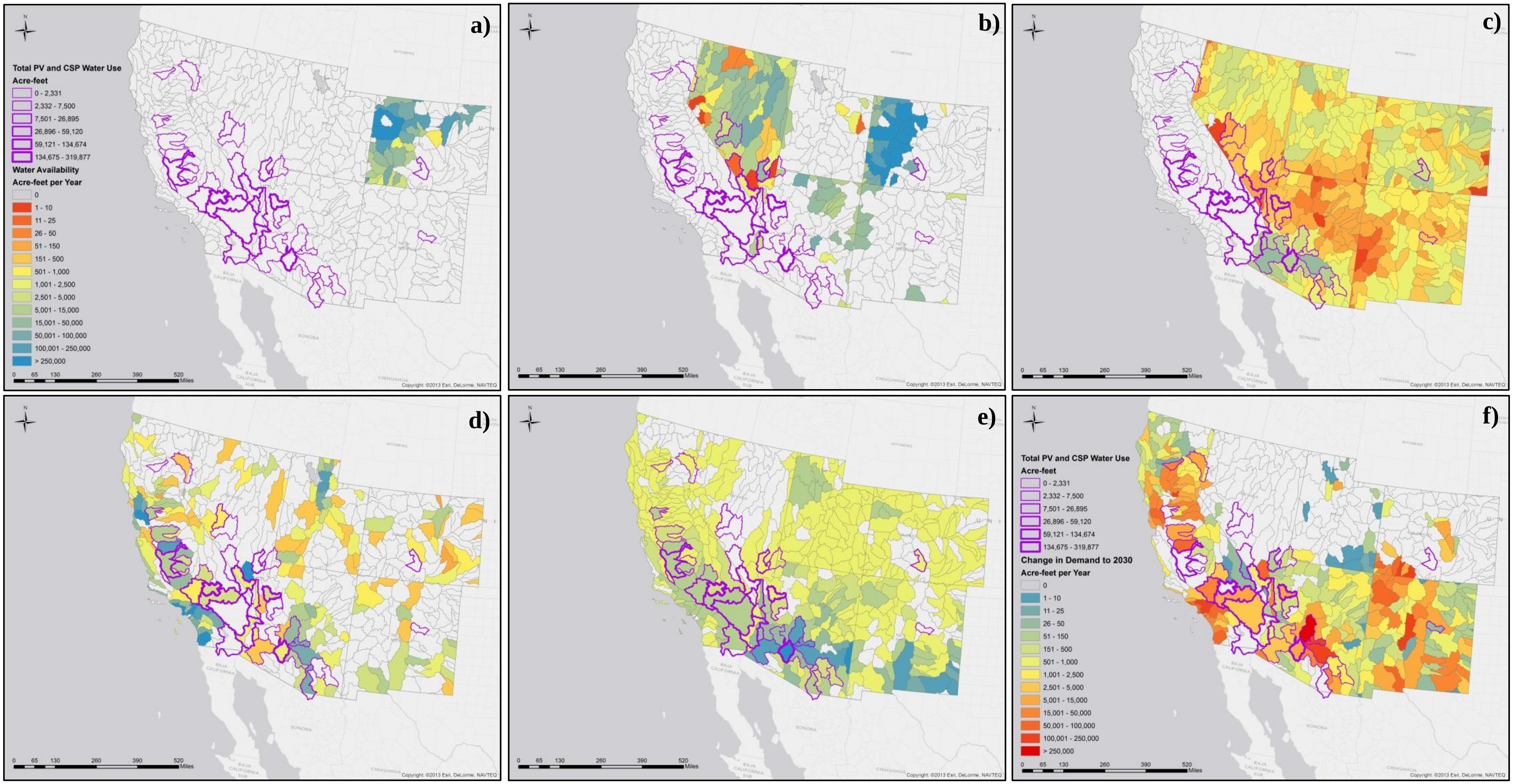

Figure 18. Total CSP and PV construction and 25-year water use from Figure 13 overlain above water availability and future demand as shown in Figure 16. Mapped are water availability metrics for a) unappropriated surface water, b) unappropriated groundwater, c) appropriated water, d) municipal waste water, e) brackish groundwater, and f) projected increase in consumptive water use between 2010 and 2030. All metrics are mapped at the 8-digit HUC level. All are mapped to a consistent non-linear color scale; however the color scheme is reversed between availability and demand (e.g., hot colors indicate limited availability and high demand). Solar water use by HUC increases by line thickness.

Table 7. Water availability by SEZ. Note that the reported water availability is for the 8-digit HUC in which the SEZ falls.

				Water Availability (AF/yr)				
State	SEZ Zone	HUC	HUC Name	Unapp. SW	Approp. Water	Unapp. Groundwater	Wastewater	Brackish Groundwater
Arizona	Brenda	15030105	Bouse Wash	0	5,182	0	0	40,996
	Gillespie	15070104	Centennial Wash	0	5,359	0	0	23,924
California	Imperial East	18100204	Salton Sea	0	0	0	0	10,298
	Riverside East	18100100	Southern Mojave	0	0	0	0	10,298
		15030104	Imperial Reservoir	0	0	0	1,680	1,120
Colorado	Fourmile East	13010003	San Luis	0	3,275	0	0	1,120
	DeTilla Gulch	13010004	Saguache	0	2,934	23,395	0	0
	Antonito Southeast	13010002	Alamosa-Trinchera	0	5,967	0	0	0
	Los Mogotes East	13010002	Alamosa-Trinchera	0	5,967	0	0	0
Nevada	Millers	16060003	Southern Big Smoky Valley	0	129	23,931	370	0
	Dry Lake Valley North	16060009	Dry Lake Valley	0	412	7,441	0	0
	Gold Point	16060013	Cactus-Sarcobatus Flats	0	214	1,932	0	0
	Mamargosa Valley	18090202	Upper Amargosa	0	215	673,369	0	0
	Dry Lake	15010012	Muddy	0	170	21,516	0	1,120
New Mexico	Afton	13030102	El Paso-Las Cruces	0	2,257	0	0	28,000
Utah	Wah Wah Valley	16030009	Sevier Lake	0	1,091	0	0	1,120
	Milford Flats South	16030007	Beaver Bottoms-Upper Beaver	0	1,102	0	0	0
	Escalante Valley	16030006	Escalante Desert	0	2,690	0	0	2,387

5. Discussion and Summary

Review of solar facility siting documents suggests several approaches to meeting water need. In some cases use of an on-site well is proposed, while in other cases water will be brought in from off-site, depending on the sensitivity of the ground water in that watershed, or the economics of on-site pumping versus delivery from a different location. Additionally, treated wastewater is identified for cooling at CSP facilities, however in most cases that wastewater is already being treated and being put to beneficial use for industrial operations, irrigation or aquifer storage and recovery.

There is obviously a large emphasis on reducing the cooling technology water usages, as evidenced towards the trend for more hybrid or dry-cooled facilities. However, it is unclear if this trend towards greater efficiency will be applied to reducing water needs for the construction phase of the project. As shown for PV facilities (e.g., Figure 4), the construction water use is significantly higher than any O&M water use over the lifetime of the PV facility. This presents an opportunity for technologies for reducing water used during the construction phase for all large utility-scale solar power plants. Technical challenges that remain to reduce fugitive dust emissions due to air quality regulations include whether additives, stabilizers or surfactants can be used on soil at these facilities with minimal or no harm to the surrounding environment.

Most importantly, what is shown are *estimates* for large-scale construction and O&M water use, as data on these facilities is far and few between, primarily because these large facilities have not yet been built, and estimates are based on extrapolations from construction and O&M for small PV facilities and power plant construction estimates in arid locations. Once these large facilities are completed, and water use estimates are reported to the BLM, EIA and other agencies, a more accurate representation of actual water usage for construction and O&M will be available. Until then, these estimates are a 'first-cut' at consolidating these large facilities either operating, under construction or under development, and understanding their potential impacts to watersheds at risk in light of competing uses.

Potential water use was found to vary considerably by region. Specifically, for the 31 SEZ's considered, total water required during construction ranges from 0.2 acre-feet/megawatt (AF/MW) (4,674 AF for a 17,043-MW Parabolic Trough plant) to 7 AF/MW (3,409 AF for a 508-MW PV plant). Total operational water use for a dry-cooled system could be as high as 2.16 AF/MW/yr (368 AF/yr for a 170-MW Parabolic Trough plant) to as low as 0.23 AF/MW/yr (2,864 AF/yr for a 12,300-MW Parabolic Trough plant), while a wet-cooled system ranged as high as 21.48 AF/MW/yr (3,656 AF/yr for a 170-MW Parabolic Trough plant) and as low as 1.63 AF/MW/yr (11,167 AF/yr for a 6,833-MW Power Tower). Total operational water includes water for panel/mirror washing, potable supply for the workforce, and cooling. In all cases, water use requirements during the peak construction year are likely to be greater than the average annual recharge to the basin but constitute a minor portion of current groundwater withdrawals and estimated groundwater storage in the basin.

Mapping projected water demands with water availability indicates some important mismatches. Except in a few limited cases, there is no availability of unappropriated surface water and limited availability of wastewater and unappropriated groundwater. In contrast, brackish groundwater is available in many developing basins and appropriated water may also be potentially available. Many of the watersheds in California and Arizona will have to balance demands for solar development with that of other water use sectors. Of most concern are ten watersheds (9 in California and one in New Mexico) in which only one source of water is available for future development.

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Appendix 1: Water Planning Documents

State	Citation	Agency	Document	Site
Arizona	Arizona Department of Water Resources (2010). Arizona Water Atlas. http://www.azwater.gov/AzDWR/StatewidePlanning/WaterAtlas/default.htm	Arizona Department of Water Resources	Arizona Water Atlas	http://www.azwater.gov/AzDWR/StatewidePlanning/WaterAtlas/default.htm
California	California Department of Water Resources. (2009) California Water Plan Update 2009. Bulletin 160-09. Sacramento, CA. http://www.waterplan.water.ca.gov/cwpu2009/index.cfm	California Department of Water Resources	California Water Plan Update 2009	http://www.waterplan.water.ca.gov/cwpu2009/index.cfm
Colorado	Colorado Water Conservation Board. (2004) Statewide Water Supply Initiative 2004. Denver, CO. http://cwcbweblink.state.co.us/WebLink/ElectronicFile.aspx?docid=144066&searchid=2c16c041-d0b2-4ec5-ac42-8b95aa0c04e3&dbid=0	Colorado Water Conservation Board, Colorado Department of Natual Resources	Statewide Water Supply Initiative 2004	http://cwcb.state.co.us/public-information/publications/pages/studiesreports.aspx
Colorado	Colorado Water Conservation Board. (2011) Statewide Water Supply Initiative 2010. http://cwcb.state.co.us/water-management/water-supply-planning/Documents/SWSI2010/SWSI2010.pdf	Colorado Water Conservation Board, Colorado Department of Natual Resources	Statewide Water Supply Initiative 2010	http://cwcb.state.co.us/water-management/water-supply-planning/pages/swsi2010.aspx
Colorado	Ivahnenko, Tamara and Flynn, J.L., 2010, Estimated withdrawals and use of water in Colorado, 2005: U.S. Geological Survey Scientific Investigations Report 2010-5002, 61 p.	USGS in cooperation with the Colorado Water Conservation Board	Estimated Withdrawals and Use of Water in Colorado, 2005	http://pubs.usgs.gov/sir/2010/5002/
Colorado	BBC Research & Consulting. Yampa Valley Water Demand Study. http://www.crwcd.org/media/uploads/Elk_Yampa_water_demand.pdf	U.S. Fish and Wildlife Service	Yampa Valley Water Demand Study	http://www.crwcd.org/media/uploads/Elk_Yampa_water_demand.pdf
Idaho	Idaho Department of Water Resources. *Idaho Geographic Information Systems Data.*	Idaho Department of Water Resources		http://www.idwr.idaho.gov/GeographicInfo/GISdata/gis_data.htm
Idaho	Idaho Department of Water Resources web page.	Idaho Department of Water Resources	No document. Information can be found here on spatial data, water supply information, groundwater levels, groundwater management, etc...	http://www.idwr.idaho.gov/
Kansas (1)	Kansas Department of Agriculture. (2010) Kansas Municipal Water Use 2010. Topeka, KS: Division of Water Resources. http://www.ksda.gov/includes/document_center/dwr/Publications/2010_KS_Municipal_Water_Use.pdf	Kansas Department of Agriculture, Division of Water Resources	Kansas Municipal Water Use 2010	http://www.ksda.gov/includes/document_center/dwr/Publications/2010_KS_Municipal_Water_Use.pdf
Kansas (2)	Kansas Department of Agriculture. (2010) Kansas Irrigation Water Use 2010. Topeka, KS: Division of Water Resources. http://www.ksda.gov/includes/document_center/dwr/Publications/2010_Irrigation_Water_Use.pdf	Kansas Department of Agriculture, Division of Water Resources	Kansas Irrigation Water Use 2010	http://www.ksda.gov/includes/document_center/dwr/Publications/2010_Irrigation_Water_Use.pdf

State	Citation	Agency	Document	Site
Montana	Montana Department of Revenue Irrigated Acres Coverage	Montana Department of Revenue		
Montana	Resources Division. Montana's State Water Plan. http://dnrc.mt.gov/wrd/water_mgmt/montana_state_waterplan/default.asp	Natural Resources and Conservation, Water Resources Division	There is no cohesive document but the parts can be found on the website.	http://dnrc.mt.gov/wrd/water_mgmt/montana_state_waterplan/default.asp
Nebraska* (1)	U.S. Geological Survey. (2005) Water Use in Nebraska, 2005. ne.water.usgs.gov/infodata/wateruse	U.S. Geological Survey	Water Use in Nebraska, 2005.	ne.water.usgs.gov/infodata/wateruse
Nebraska* (2)	Nebraska Department of Natural Resources.(2012) NebraskaMAP GeoPortal. Registered Groundwater Wells. Www.nebraskamap.gov	Nebraska Department of Natural Resources	NebraskaMap Geoportal contains geospatial data of approved groundwater wells.	oportal/catalog/main/home.page;jsessionid=F723792C157CBEA759B0158AD1F78CD2
Nebraska* (3)	Evaluation of Availability of Hydrologically Connected Water Supplies. Lincoln, NE. http://dnr.ne.gov/IWM/AnnualReport/2006_AnnualReport.pdf	Nebraska Department of Natural Resources	2006 Annual Evaluation of Availability of Hydrologically Connected Water Supplies	http://dnr.ne.gov/IWM/AnnualReport/2006_AnnualReport.pdf
Nevada	Nevada Division of Water Planning. (1999) Nevada State Water Plan. Carson City, NV.	State of Nevada Division of Water Resouces	Nevada State Water Plan	http://water.nv.gov/programs/planning/stateplan/
New Mexico	New Mexico Office of the State Engineer. (2005) New Mexico Water Use by Categories. Technical Report 52.	Office of the State Engineer	New Mexico Water Use by Categories 2005, Technical Report 52	http://www.ose.state.nm.us/PDF/Publications/Library/TechnicalReports/TechReport-052.pdf
North Dakota (1)	North Dakota State Water commission. (2012) General Water Resource MapService. Http://mapservice.swc.nd.gov.	North Dakota State Water Commission	MapService is an online mapping program that contains all water permit data for the state.	http://mapservice.swc.nd.gov/
North Dakota (2)	North Dakota State Water Commission. (2009) State Water Management Plan. Bismarck, ND. http://www.swc.state.nd.us/4dlink9/4dcgi/GetContentPDF/PB-1349/SWMP09Report.pdf	North Dakota State Water Commission	North Dakota State Water Management Plan	http://www.swc.state.nd.us/4dlink9/4dcgi/GetContentPDF/PB-1349/SWMP09Report.pdf

*State with no formal water plan

State	Citation	Agency	Document	Site
Oklahoma	Oklahoma Water Resources Board. (2012) Oklahoma Comprehensive Water Plan 2012. Oklahoma City, OK. Www.owrb.ok.gov/supply/ocwp/ocwp.php	Oklahoma Water Resources Board	Oklahoma Comprehensive Water Plan 2012	www.owrb.ok.gov/supply/ocwp/ocwp.php
Oregon	Oregon Water Resources Department (2009). An Introduction to Oregon's Water Laws: Water Rights in Oregon. http://www.oregon.gov/owrd/pages/pubs/aquabook.aspx	Oregon Water Resources Department	An Introduction to Oregon's Water Laws: Water Rights in Oregon. "Aquabook"	http://www.oregon.gov/owrd/pages/pubs/aquabook.aspx
Oregon	Oregon Water Supply and Conservation Initiative (2008). Statewide Water Needs Assessment. http://www.oregon.gov/owrd/law/docs/owsci/owrd_demand_assessment_report_final_september_2008.pdf	Oregon Water Resources Department	Statewide Water Needs Assessment	http://www.oregon.gov/owrd/law/docs/owsci/owrd_demand_assessment_report_final_september_2008.pdf
Oregon	Oregon Water Resources Department Webpage. http://www.oregon.gov/owrd/Pages/index.aspx	Oregon Water Resources Department	Information can be found here on surface water, groundwater, storage, etc...	http://www.oregon.gov/owrd/Pages/index.aspx
South Dakota*	Carter, Janet M. and Kathleen M. Neitzert. (2008) Estimated Use of Water in South Dakota, 2005. Reston, VA: US Geological Survey. 2008-5216. http://pubs.usgs.gov/sir/2008/5216/pdf/sir2008-5216.pdf	Estimated Use of Water in South Dakota, 2005	Estimated Use of Water in South Dakota	http://pubs.usgs.gov/sir/2008/5216/pdf/sir2008-5216.pdf
Texas	Water Plan. http://www.twdb.state.tx.us/publications/state_water_plan/2012/2012_SWP.pdf	Texas Water Development Board	Water For Texas 2012 State Water Plan	http://www.twdb.state.tx.us/publications/state_water_plan/2012/2012_SWP.pdf
Utah	Utah Divison of Water Resources Webpage. http://www.water.utah.gov/	Utah Division of Water Resources	Information can be found on water use, policy, etc...	http://www.water.utah.gov/
Washington*	State of Washington Department of Ecology, Water Resources Web page. http://www.ecy.wa.gov/programs/wr/wrhome.html	State of Washington Department of Ecology	No document. Information can be found here on spatial data, water supply information, groundwater levels, groundwater management, etc...	http://www.ecy.wa.gov/programs/wr/wrhome.html
Wyoming	Wyoming Water Development Commission. (2007) Wyoming Framework Water Plan. http://waterplan.state.wy.us/frameworkplan-index.html	Wyoming Water Development Commission	The Wyoming Framework Water Plan	http://waterplan.state.wy.us/frameworkplan-index.html

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