ANL/EVS-14/2

Geothermal Water Use: Life Cycle Water Consumption, Water Resource Assessment, and Water Policy Framework

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Environmental Science Division

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Geothermal Water Use: Life Cycle Water Consumption, Water Resource Assessment, and Water Policy Framework

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NOTATION

The following is a list of acronyms, abbreviations, and units of measure used in this report.

GENERAL ACRONYMS AND ABBREVIATIONS

Argonne	Argonne National Laboratory
ARS	*Arizona Revised Statutes*
BLM	U.S. Bureau of Land Management
CA PRC	*California Public Resources Code*
CSP	concentrating solar power
CFR	*Code of Federal Regulations*
DOE	U.S. Department of Energy
DOGAMI	Department of Geology and Mineral Industries (Oregon)
DOI	U.S. Department of the Interior
EGS	enhanced geothermal system
EIA	Energy Information Administration
EMNRD	Energy Minerals and Natural Resources Department (New Mexico)
EPA	U.S. Environmental Protection Agency
GEA	Geothermal Energy Association
GETEM	Geothermal Electricity Technology Evaluation Model
GPRA	Government Performance and Results Act
GRR	Geothermal Regulatory Roadmap
GTO	Geothermal Technologies Office (DOE)
HUC	hydrologic unit code
IS	*Idaho Statutes*
LCA	life cycle analysis
LCOE	levelized cost of energy
NDWR	State of Nevada Division of Water Resources
NEMS	National Energy Modeling System
NGWA	National Ground Water Association
NREL	National Renewable Energy Laboratory
NRS	*Nevada Revised Statutes*

OAR	*Oregon Administrative Rule*
ORS	*Oregon Revised Statutes*
PV	photovoltaic
TDS	total dissolved solids
UC	*Utah Code*
USFS	U.S. Forest Service
USGS	U.S. Geological Survey

UNITS OF MEASURE

°C	degree(s) Celsius
°F	degree(s) Fahrenheit
ft	foot (feet)
gal	gallon(s)
GW	gigawatt(s)
kg	kilogram(s)
km	kilometer(s)
kWh	kilowatt hour(s)
L	liter(s)
m	meter(s)
mg	milligram(s)
MW	megawatt(s)
MWe	megawatt(s) electric
MWh	megawatt hour(s)
ppm	part(s) per million
s	second(s)
yr	year(s)

1 INTRODUCTION

According to the Energy Information Administration (EIA) of the U.S. Department of Energy (DOE), geothermal energy generation in the United States is projected to more than triple by 2040 (EIA 2013). This addition of more than 5 GW of generation capacity is anticipated because of technological advances and an increase in available sources through the continued development of enhanced geothermal systems (EGSs) and low-temperature resources (EIA 2013). Although studies have shown that air emissions, water consumption, and land use for geothermal electricity generation have less of an impact than traditional fossil fuel–based electricity generation, the long-term sustainability of geothermal power plants can be affected by insufficient replacement of aboveground or belowground operational fluid losses resulting from normal operations.

This report examines life cycle water consumption for various geothermal technologies to better understand factors that affect water consumption across the life cycle (e.g., power plant cooling, belowground fluid losses) and to assess the potential water challenges that future geothermal power generation projects may face. Previous reports in this series quantified the life cycle freshwater requirements of geothermal power-generating systems, explored operational and environmental concerns related to the geochemical composition of geothermal fluids, and assessed future water demand by geothermal power plants according to growth projections for the industry.

The initial life cycle analysis (LCA) of freshwater consumption of geothermal power-generating systems identified that operational water requirements consume the vast majority of water across the life cycle for hydrothermal binary, hydrothermal flash, and EGSs with binary power generation (Clark et al. 2011). That analysis relied upon limited operational water consumption data and did not account for belowground operational losses for EGSs.

A second report extended the LCA to include geopressured geothermal systems and presented an initial assessment of freshwater demand for future growth in utility-scale geothermal power generation (Clark et al. 2012).

The third report built upon this work to improve life cycle freshwater consumption estimates, accounting for belowground operational losses, and incorporated regional water availability into the resource assessment to improve the identification of areas where future growth in geothermal electricity generation may encounter water challenges (Clark et al. 2013).

This report seeks to extend those analyses by including EGS flash, both as part of the life cycle analysis and water resource assessment. It also analyzes the legal framework of water with respect to geothermal resources in the states with active geothermal development.

1.1 PURPOSE AND OVERVIEW OF STUDY

The methods used in this report closely follow those employed in previous Argonne National Laboratory (Argonne) reports on this topic, notably Sullivan et al. (2010) and Clark et al. (2011, 2012, and 2013). As in the previous reports, a number of hypothetical geothermal power plants were evaluated during the LCA.

The report is organized as follows. Chapter 2 extends the life cycle analysis previously developed and described in Clark et al. (2013) to evaluate water consumption for new technology scenarios, including EGS flash systems, and to understand how technology improvements could impact life cycle water consumption.

Chapter 3 presents a regional water resource assessment based upon the life cycle results in Chapter 1. The assessment includes more scenarios that consider different assumptions about geothermal systems designs and cooling systems than presented in Clark et al. (2013). Select scenarios of projected future water consumption were also directly compared with estimates of future water availability for individual hydrological basins.

Chapter 4 presents an analysis of definitions for water, freshwater, groundwater, and geothermal waters from a legal perspective. A comprehensive analysis of relevant federal laws and regulations was conducted, as well as a thorough, state-by-state review for all mainland western states with active geothermal energy projects.

Chapter 5 presents a summary and conclusions, and Chapter 6 lists the references used to prepare this report.

2 LIFE CYCLE ASSESSMENT

2.1 METHODS

A standardized set of scenarios was developed by the DOE Geothermal Technologies Office (GTO) with input from national laboratory and industry experts (see Tables 1 and 2) for evaluation of the levelized cost of electricity (LCOE) and the associated environmental impacts of geothermal technologies. These scenarios were provided by the GTO for consistency between this and any other analyses that might rely on these scenarios, such as Sullivan et al. (2013). The scenarios were run in DOE's Geothermal Electricity Technology Evaluation Model (GETEM) repetitively to create a range of possible outcomes by varying select parameters. Key parameter values from the scenario definitions and select GETEM outputs were then used to help calculate the life cycle water consumption for each scenario. These included, but were not limited to, the number of production and injection wells, the well flow rates, the water consumption for flash system cooling, and the plant lifetime.

GTO developed 10 scenarios; half of which focus on hydrothermal plants and half of which focus on EGS power plants. Each scenario was run in GETEM with a "Reference" set of parameters and an "Improved" set of parameters to create a total of 20 scenarios. For the EGS scenarios, the Improved scenarios were developed to reduce the LCOE for that configuration by some combination of increased well flow rate, capacity, extended plant lifetime, reduced thermal drawdown rate, exploration well sites, and finally, alternative financing (Sullivan et al. 2013). For the hydrothermal binary scenario, reductions in LCOE were primarily brought about by increasing the number of production wells at constant well flow rates and hence, plant capacity (Sullivan et al. 2013). In addition, the difference in the scenarios also involved forecasting the level of technology available in the future. For example, the EGS Reference scenarios were run assuming current technology available in 2012. However, EGS Improved scenarios were run assuming technological breakthroughs available in 2030, which would help lower the LCOE. For example, increased engineering efficiency available in 2030 would, it was assumed, allow operators to extract heat more efficiently, both technically and economically. Better exploration technology would mean fewer exploration well sites. Better drilling technology would lead to reservoirs that are more efficiently connected, leading to less water loss. These assumptions are also true of the Improved Hydrothermal scenarios, with the exception that the forecast was out to 2020, not 2030.

Several new technology scenarios were employed. Previously, it was assumed that the EGS would rely upon binary technology for electric power generation. This report presents several flash EGS scenarios. Also, subsurface water loss was investigated across the range of EGS scenarios, providing more insight into the role that resource temperature has on this key life cycle stage. Loss rates of either 1% or 5% were analyzed as specified in the scenario definitions. The 5% loss rate is consistent with data from the limited number of EGS test projects to date, while the 1% value has been achieved at one site and may be achievable at additional sites in the future with improved understanding of these systems and the causes of belowground water loss. Finally, life cycle impacts associated with sand mining for proppants were not investigated, as existing U.S. EGS projects are not using proppants at this time.

TABLE 1 GETEM EGS Scenarios[a]

Parameter	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5	
	Reference	**Improved**	**Reference**	**Improved**	**Reference**	**Improved**	**Reference**	**Improved**	**Reference**	**Improved**
Power sales (MW)	10	25	15	35	20	40	25	50	30	50
Generator type	Binary	Binary	Binary	Binary	Binary	Binary	Flash	Flash	Flash	Flash
Cooling type	Air	Air	Air	Air	Air	Air	Wet	Wet	Wet	Wet
Temperature (°C)	100	100	150	150	175	175	250	250	325	325
Injection to production ratio	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Well depth (km)	2	2	2.5	2.5	3	3	3.5	3.5	4	4
Production flow rate (kg/s)	40	100	40	100	40	100	40	80	40	80
Subsurface water loss (% produced flow)	5	1	5	1	5	1	5	1	5	1
Plant lifetime (yr)	20	30	20	30	20	30	20	30	20	30
Well field stimulation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Flash steam cycle water loss (%)	*0*	*0*	*0*	*0*	*0*	*0*	*23.2*	*23.6*	*29.8*	*30.3*
Number of production wells	*22*	*23*	*8*	*9*	*8*	*8*	*6*	*6*	*4*	*3*
Number of injection wells	*11*	*11*	*4*	*5*	*4*	*4*	*3*	*3*	*2*	*2*

[a] Italicized information represents data that were output from GETEM.

TABLE 2 GETEM Hydrothermal Scenarios[a]

	Scenario 6		Scenario 7		Scenario 8		Scenario 9		Scenario 10	
Parameter	**Reference**	**Improved**	**Reference**	**Improved**	**Reference**	**Improved**	**Reference**	**Improved**	**Reference**	**Improved**
Power sales (MW)	15	20	30	50	30	50	40	50	15	25
Generator type	Binary	Binary	Flash	Flash	Binary	Binary	Flash	Flash	Binary	Binary
Cooling type	Air	Air	Wet	Wet	Air	Air	Wet	Wet	Air	Air
Temperature (°C)	140	140	175	175	175	175	225	225	140	140
Injection to production ratio	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Well depth (km)	1.5	1.5	1.5	1.5	1.5	1.5	2.5	2.5	2.5	2.5
Production flow rate (kg/s)	100	100	80	80	100	100	80	80	100	100
Subsurface water loss (% produced flow)	0	0	0	0	0	0	0	0	0	0
Plant lifetime (yr)	30	30	30	30	30	30	30	30	30	30
Well field stimulation	No	No	No	No	No	No	No	No	No	No
Flash steam cycle water loss (%)	*0*	*0*	*15.5*	*15.5*	*0*	*0*	*22.5*	*22.3*	*0*	*0*
Number of production wells	*5*	*9*	*9*	*15*	*6*	*11*	*6*	*7*	*4*	*8*
Number of injection wells	*4*	*7*	*7*	*11*	*5*	*8*	*5*	*6*	*3*	*6*

[a] Italicized information represents data that were output from GETEM.

The different life cycle stages represented in this analysis are defined below. The first stage, Drilling and Construction, includes all water consumed during well drilling, pipeline construction, and power plant construction. As in previous analyses (Clark et al. 2010, 2011), this stage does *not* include the wellhead apparatus, but instead, all components belowground, including all liners and casings. Pipelines include pipeline, pipeline supports, and support footings.

Stimulation and Circulation Testing stages are more straightforward and include consumptive losses from all fluids injected underground for the purposes of stimulating an EGS reservoir, and then, subsequently, testing the circulation of this enhanced reservoir. Although additives, such as tracers, diverters, chelating agents, and several others, are present in these fluids (see Clark et al. 2013 for more information on chemicals used in stimulation activities), it was assumed for the purpose of this analysis that the volumes are 100% water. This is because while additives may be present, they typically represent a small percentage of the total fluid sent downhole (Clark et al. 2013).

As mentioned previously, Belowground Operational Losses, otherwise known as reservoir loss, were assumed to be either 1% or 5%, depending on the scenario analyzed. These values are based on past research into actual losses at real-world EGS projects, which showed these values to be within the range experienced at these facilities (Chabora et al. 2012; Portier et al. 2009; Zimmermann and Reinicke 2010; Schindler et al. 2010). Aboveground Operational Losses include all water consumed during operation of the plant itself, including losses from cooling and makeup.

Finally, Non-Cooling Associated Losses is a category meant to encompass all other losses not included in the other life cycle stages. It is a constant value of 40 gallons per megawatt hour (gal/MWh), which is based on the average water consumption of a dry-cooled binary system, which because the cooling system does not consume any water, represents the water consumption from non-cooling related activities, such as dust suppression, maintenance, and domestic use (Clark et al. 2013).

2.2 RESULTS

Life cycle results are summarized in Tables 3 and 4. Table 3 summarizes water consumption by life cycle stage for EGS scenarios, and Table 4 does the same for hydrothermal scenarios. A few key parameters, such as capacity, well depth, temperature, flow rate, and cooling technology are included at the top of each scenario. In addition, the percentage of total consumption that each life cycle stage represents is given beneath the quantity as a percentage.

2.2.1 Operational Losses versus Construction and Drilling Losses

Overall, the water loss for the construction and drilling phase was found to be extremely small when compared with the total water loss for all scenarios analyzed. For the EGS scenarios, consumptive losses from drilling and construction composed between 0.02% and 0.34% of the

TABLE 3 Life Cycle Water Consumption Summary for EGS Scenarios[a]

	Scenario 1		**Scenario 2**		**Scenario 3**		**Scenario 4**		**Scenario 5**	
	Reference	***Improved***	***Reference***	***Improved***	***Reference***	***Improved***	***Reference***	***Improved***	***Reference***	***Improved***
Parameter	*EGS Binary Air-Cooled*		*EGS Binary Air-Cooled*		*EGS Binary Air-Cooled*		*EGS Flash Wet-Cooled*		*EGS Flash Wet-Cooled*	
Capacity (MW)	10	25	15	35	20	40	25	50	30	50
Start year	2012	2030	2012	2030	2012	2030	2012	2030	2012	2030
Well depth (km)	2	2	2.5	2.5	3	3	3.5	3.5	4	4
Temperature (°C)	100	100	150	150	175	175	250	250	325	325
Flow rate (kg/s)	40	100	40	100	40	100	40	80	40	80
Drilling and construction loss	9.0	2.6	2.7	0.98	2.4	0.79	2.0	0.54	1.4	0.40
(gal/MWh)[b]	0.21%	0.28%	0.27%	0.32%	0.29%	0.34%	0.07%	0.02%	0.07%	0.03%
Stimulation water consumption	32	9.3	7.8	2.8	5.8	1.9	4.7	1.2	2.9	0.8
(gal/MWh)	0.76%	1.01%	0.76%	0.92%	0.72%	0.84%	0.17%	0.05%	0.15%	0.05%
Circulation testing water consumption	29	8.4	7.0	2.5	5.3	1.8	4.2	1.1	2.6	0.0
(gal/MWh)	0.69%	0.91%	0.69%	0.83%	0.65%	0.76%	0.15%	0.05%	0.14%	0.00%
Belowground operational loss	4,100	860	960	260	750	190	490	87	270	49
(gal/MWh)	97.38%	93.48%	94.37%	84.67%	93.36%	80.66%	17.40%	3.98%	14.01%	3.11%
Cooling-related losses	0.0	0.0	0.0	0.0	0.0	0.0	2,300	2,048	1,600	1,500
(gal/MWh)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	80.78%	94.05%	83.52%	94.26%
Non-cooling associated consumption	40	40	40	40	40	40	40	40	40	40
(gal/MWh)	0.95%	4.33%	3.92%	13.26%	4.97%	17.40%	1.43%	1.84%	2.11%	2.56%
Totals										
Freshwater consumption (gal/MWh)	110	60	58	46	53	44	51	43	47	41
Geofluid loss (gal/MWh)	4,100	860	960	260	750	190	2,700	2,100	1,900	1,500
Geofluid makeup (gal/MWh)	4,100	860	960	260	750	190	2,700	2,100	1,900	1,500
Water consumption (gal/MWh)	4,200	920	1,000	300	800	230	2,800	2,200	1,900	1,600

[a] Geofluid losses may occur aboveground (i.e., flash) or belowground (i.e., EGS). Geofluid is not necessarily lost in all scenarios.

[b] The sum of the percentage contribution of water loss for each life cycle stage may not be 100% due to rounding.

TABLE 4 Life Cycle Results for Hydrothermal Scenarios[a]

Parameter	Scenario 6		Scenario 7		Scenario 8		Scenario 9		Scenario 10	
	Reference	***Improved***	***Reference***	***Improved***	***Reference***	***Improved***	***Reference***	***Improved***	***Reference***	***Improved***
	Hydrothermal Binary Air-Cooled		*Hydrothermal Flash Wet-Cooled*		*Hydrothermal Binary Air-Cooled*		*Hydrothermal Flash Wet-Cooled*		*Hydrothermal Binary Air-Cooled*	
Capacity (MW)	15	20	30	50	30	50	40	50	15	25
Start year	2012	2020	2012	2020	2012	2020	2012	2020	2012	2020
Well depth (ft)	1.5	1.5	1.5	1.5	1.5	1.5	2.5	2.5	2.5	2.5
Temperature (°C)	140	140	175	175	175	175	225	225	140	140
Flow rate (kg/s)	100	100	80	80	100	100	80	80	100	100
Drilling and construction loss (gal/MWh)[b]	0.77 1.89%	0.96 2.36%	0.73 1.79%	0.64 1.58%	0.52 1.27%	0.49 1.21%	1.0 2.48%	0.95 2.32%	2.0 4.84%	1.90 4.53%
Stimulation water consumption (gal/MWh)	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%
Circulation testing water consumption (gal/MWh)	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%
Belowground operational loss (gal/MWh)	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%
Cooling-related losses (gal/MWh)	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%	0.0 0.00%
Non-cooling associated consumption (gal/MWh)	40 98.11%	40 97.64%	40 98.21%	40 98.42%	40 98.73%	40 98.79%	40 97.52%	40 97.68%	40 95.16%	40 95.47%
Totals										
Freshwater consumption (gal/MWh)	41	41	41	41	41	40	41	41	42	42
Geofluid loss (gal/MWh)	0.0	0.0	3,600	3,500	0.0	0.0	2,600	2,500	0.0	0.0
Geofluid makeup (gal/MWh)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water consumption (gal/MWh)	41	41	41	41	41	40	41	41	42	42

[a] Geofluid losses may occur aboveground (i.e., flash) or belowground (i.e., EGS). Geofluid is not necessarily lost in all scenarios.

[b] The sum of the percentage contribution of water loss for each life cycle stage may not be 100% due to rounding.

total water consumption for each scenario. These percentages went up slightly for the hydrothermal scenarios, with well drilling and construction making up 1.2% and 4.8% of total water consumption. These findings are in line with previous findings, which suggest that operational losses are by far the major contributor to geothermal water consumption (Clark et al. 2011, 2013).

2.2.2 EGS Binary versus EGS Flash

In all EGS scenarios, losses from the operational phase dominated, both aboveground and belowground. For the air-cooled EGS binary scenarios, belowground reservoir loss dominated and accounted for 80.6% to 97.4% of the total water consumption. For wet-cooled EGS flash scenarios, aboveground operational losses dominated. This is due to significant makeup water losses in the flash system scenarios, between approximately 23% and 30%, depending on the scenario according to GETEM. These losses occur because of (1) flashing of the geofluid and incomplete condensing of the fluid, and (2) the wet cooling system assumption used for these systems, which assumes that a portion of the produced geofluid condensate will be diverted to cool the system. Some of the condensate used for cooling water is lost via the cooling tower through blowdown, drift, or evaporative losses. Binary systems that are air-cooled do not experience these losses.

2.2.3 Hydrothermal Binary versus Flash

For hydrothermal scenarios, non-cooling associated losses dominated at greater than 95% for all scenarios because of the assumption that for wet-cooled flash hydrothermal systems, flash losses of geofluid were not replaced with freshwater. Although this leaves the long-term sustainability of the reservoir vulnerable, it is an industry practice to date to not replace lost geofluid. Therefore, one can see that for those systems, geofluid losses were high, but total freshwater consumption was actually very low, particularly when compared with EGSs. However, at least two operating hydrothermal flash plants, Coso and Dixie Valley, do have existing supplementary injection augmentation programs that utilize fresh groundwater to make up for lost geofluid (BLM and U.S. Navy 2008; NDWR 2012). In these cases, freshwater consumption is significantly higher, approaching the quantity of geofluid lost.

2.2.4 Hydrothermal Water Losses versus EGS Water Losses

As mentioned previously, the differences in water consumption between the EGS and Hydrothermal scenarios were largely due to the differences inherent in these two technologies. EGS projects must first inject water underground to create a reservoir. Maintaining sufficient reservoir volume and pressure to successfully circulate fluid requires significant volumes of water through the life of the project as belowground fluid losses are expected to vary from 1% to 10%. In contrast, hydrothermal systems do not have this issue. Hydrothermal binary scenarios, which can rely on air-cooling, consume relatively little water.

In comparing water consumption between these technologies, the model shows that EGS binary systems consume between 230 gal/MWh and 4,200 gal/MWh, whereas hydrothermal binary systems consume between 40 gal/MWh and 42 gal/MWh. For flash systems, this difference between hydrothermal and EGS resources is also very pronounced, due to much of the fluid loss in the Hydrothermal scenarios being attributable to geofluid loss and not to actual freshwater consumption. Hydrothermal flash water consumption is 41 gal/MWh, and EGS flash water consumption ranges from 1,600 gal/MWh to 2,800 gal/MWh. However, this difference will shrink significantly for hydrothermal flash systems where makeup fluid is injected to improve the sustainability of the reservoir. This process was not directly modeled; however, the quantity of water that would be required can be inferred from the calculated total geofluid loss values presented in Table 4.

2.2.5 Impact of Resource Temperature

Lower temperature resources require higher total flow rates to generate the same amount of energy. This directly affects two variables that impact water consumption—belowground operational losses for EGSs and the number of wells required to generate the same amount of power. Given that operational losses make up the majority of water consumption for most geothermal systems, the impact on belowground operational losses is far more significant to the overall water requirements than the impact of the number of wells drilled. For EGSs where the resource temperature is high enough that flash systems are recommended or required, the water consumption is significantly greater than for EGS binary because of the additional aboveground operational losses associated with the wet-cooled flash systems, which are typical for systems with higher resource temperatures. Figure 1 illustrates these phenomena by plotting the results of the EGS scenarios as a function of resource temperature.

2.2.6 Total Consumption by Fluid Type

Figures 2 and 3 illustrate the water consumption for the Reference and Improved scenarios, respectively, as a function of fluid type. Three different fluids were considered—freshwater, formation compatible water, and geofluid. Water consumed for drilling, stimulation, and aboveground non-cooling operational uses was assumed to be freshwater. However, water injected into the formation to compensate for aboveground or belowground operational losses need not be fresh and must only be chemically compatible with the formation and the injection well materials. Thus it is possible that many degraded or lower quality water sources can be utilized for these purposes, thereby reducing the impact of geothermal systems on freshwater resources. In Figure 2, this water is classified as “any water.” Potential alternative water sources that could be used for this purpose include, but are not limited to, municipal or industrial wastewater, brackish or saline groundwater, and impaired surface waters. For example, the Geysers geothermal field utilizes municipal wastewater piped from nearby municipalities to make up for aboveground operational fluid losses (Calpine 2014). Finally, geofluid consumption, while not having a direct impact on freshwater resources, does have an impact on the sustainability of the geothermal resources and is thus treated as a separate category.

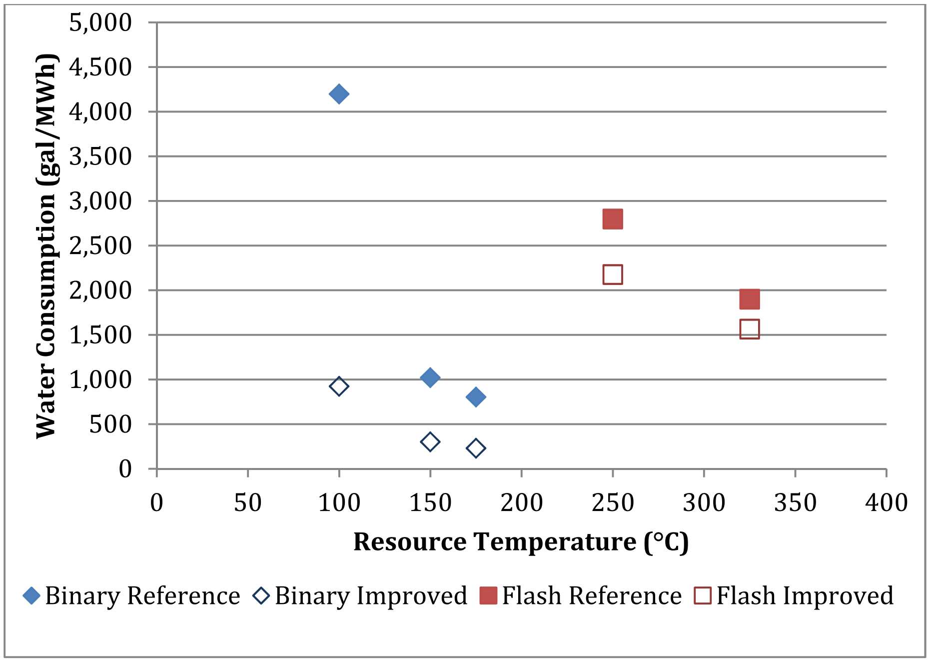

FIGURE 1 Water Consumption for EGS as a Function of Resource Temperature

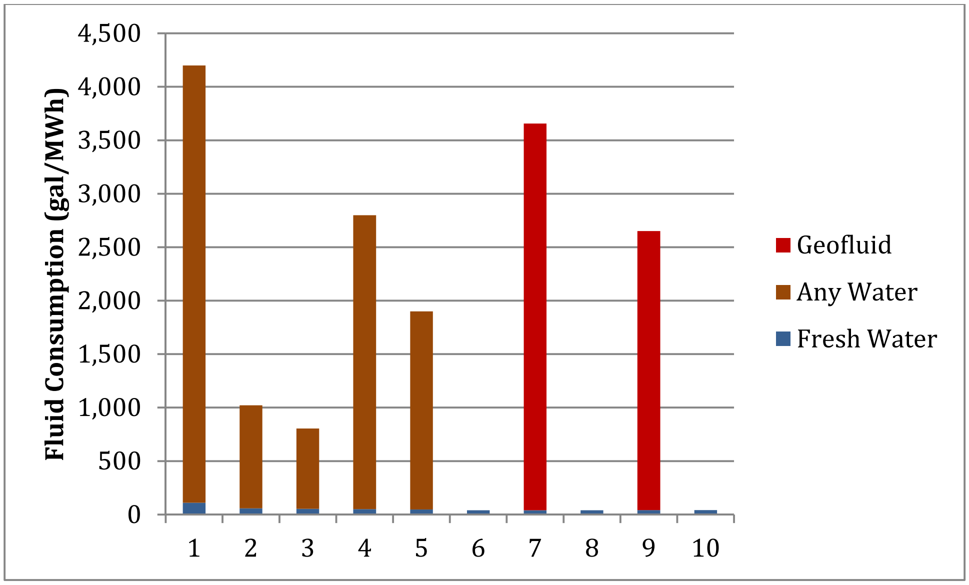

FIGURE 2 Total Fluid Consumption by Fluid Type for Reference Scenarios

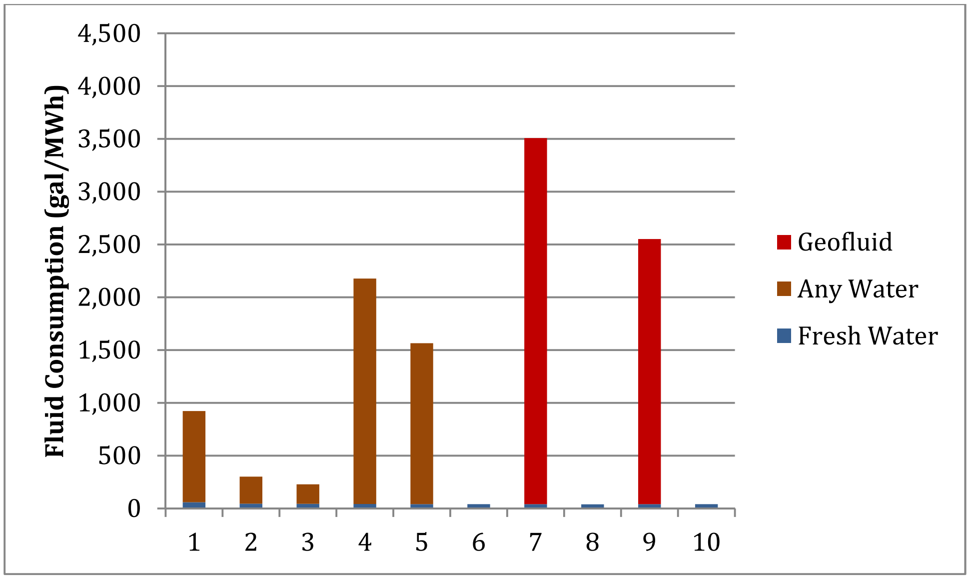

FIGURE 3 Total Fluid Consumption by Fluid Type for Improved Scenarios

The results show that although total fluid consumption for most scenarios is quite high relative to most energy systems, with a low of 40 gal/MWh for hydrothermal binary and a high of 4,200 gal/MWh for EGS binary, the consumption of fluid that would typically be freshwater for most of the scenarios is approximately 40 to 50 gal/MWh, which is significantly less than most thermoelectric generation technologies and on par with other renewables such as solar and wind. Wind power, for example, consumes 10 gal/MWh over the total life cycle (Vestas 2006). Photovoltaic (PV) solar consumes between 70 and 190 gal/MWh over the life cycle, while concentrated solar power (CSP) consumes between 870 and 1,120 gal/MWh (Harto et al. 2010; Macknick et al. 2011; DeMeo and Galdo 1997). On the other hand, cooling water consumption for non-renewable technologies like coal can range anywhere from 100 gal/MWh to 1,100 gal/MWH, depending on the type and configuration of the cooling system used (Macknick et al. 2011). Finally, nuclear water consumption ranges from 100 gal/MWh to 845 gal/MWh (Macknick et al. 2011).

More recent attempts at estimation and harmonization of literature estimates for renewable energy technologies from Meldrum et al. (2013) place CSP water consumption a bit lower, at 160 gal/MWh. Estimates for PV are more in line with past estimates, at an average of 94 gal/MWh over the total life cycle, while the average life cycle water consumption for wind is 1 gal/MWh (Meldrum et al. 2013). Finally, Meldrum's range for freshwater consumption of geothermal technologies is between 5 and 720 gal/MWh, depending on the configuration of the plant (e.g., flash, binary, or EGS) and cooling technology employed (e.g., air-cooled, hybrid-cooled, or water-cooled) (Meldrum et al. 2013). Their analysis specifically excludes water from internal sources, such as geofluid consumption. It is worth noting that when looking at only freshwater consumption, all of the scenarios presented here fit within the range presented by Meldrum et al. (2013).

In comparing water consumption between the Reference and Improved scenarios, it becomes apparent that although water consumption for the Hydrothermal scenarios is fixed at approximately 40 gal/MWh, because of the non-cooling associated consumption discussed previously, there are significant water savings between the Reference and Improved cases for the EGS scenarios. This is largely due to improved control of the reservoir in the Improved scenarios. Reservoir loss drops from 5% to 1% between these cases, and since this is the largest contributor to water consumption for EGS, it follows that improving that parameter would positively affect the water consumption numbers, as indeed is the case here.

Finally, while Argonne has not systematically investigated wet-cooling for hydrothermal binary systems in the past, because GETEM does not currently include wet cooling for hydrothermal binary systems, binary systems with hybrid cooling have been investigated. Hybrid cooling estimates collected from the literature showed that the expected range of water consumption would be between 300 and 1,700 gal/MWh (Clark et al. 2013). Further modeling of different climate zones surrounding known geothermal resources and varying operational parameters showed a similarly wide band of expected water consumption, with many values ranging from 250 to 750 gal/MWh in more temperate climates, but with water consumption exceeding 1,500 gal/MWh in some arid locations (Harto et al. 2013). Meldrum et al. (2013) cite a median water consumption value for hybrid binary systems of 460 gal/MWh, which is well within the range established in these reports.

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3 REGIONAL WATER RESOURCE ASSESSMENT

The regional water resource assessment builds upon previous Argonne work that explores the geospatial distribution of water demand for future geothermal power production (Clark et al. 2012, 2013). It combines the LCA results with a detailed supply curve for geothermal resources developed by the National Renewable Energy Laboratory (NREL) (Augustine et al. 2010). The current analysis updates the previous analysis with the latest LCA results and includes a direct comparison of water demand estimates with water availability.

3.1 METHODS

The regional water resource assessment combines the LCA results with a detailed supply curve for geothermal resources developed by NREL (Augustine et al. 2010). As previously described in Clark et al. (2013), NREL used the GETEM (DOE 2011) to model the electricity generation capacity (MWe) and estimate the LCOE ($/kWh) of geothermal resources. The LCOE was estimated by using two sets of cost assumptions: (1) a "base" case that assumed current costs with minimal technological improvements, and (2) a "target" case that assumed a reduction in cost over time for EGSs resulting from learning and technological improvement due to continued federal investment in research, development, and demonstration projects (Augustine et al. 2010). These two sets of LCOE values were used to develop two separate supply curves that were used throughout this analysis and are hereafter referred to as "base" and "target." Within the geothermal supply curve, geothermal resources were broken down into four resource categories: identified hydrothermal, unidentified hydrothermal, near-field EGS, and green-field EGS.

A total of six geothermal growth scenarios were evaluated with the new LCA results. These growth scenarios were selected from the set of scenarios previously presented in Clark et al. (2013) for consistency. Table 5 gives the key assumption for each scenario and the LCA values used for each type of power plant. Scenarios 1, 2, and 5 estimate water consumption assuming the development of all resources with an estimated LCOE below a specific cost. Scenarios 3, 4, and 6 are based upon model results projecting future growth in geothermal electricity demand by a specific date. Scenarios 3 and 6 are based upon results from a version of the National Energy Modeling System (NEMS) model designed for the Government Performance and Results Act (GPRA). Scenario 4 relies on output from the EIA version of the NEMS model. The models contain different internal assumptions about the cost and availability of geothermal as compared with other resources, with the NEMS-GPRA model incorporating the latest geothermal supply curve data, while the EIA model does not.

All scenarios in this current analysis are based upon the NREL "target" cost curve, which assumes incremental improvements in technology resulting in reduced costs for both hydrothermal and EGS by 2030. Water consumption estimates for scenarios 1 through 4 are based upon the LCA results for GTO Reference scenarios. Water consumption estimates for scenarios 5 and 6 are based upon the LCA results for the GTO Improved scenarios. The estimated future incremental water demand is mapped for each scenario based upon

TABLE 5 Regional Water Resource Assessment Scenario Parameters

Scenario	Basis	LCA Scenarios	New Generation (MWe)	LCA (gal/kWh) values used by resource type and temperature (°C)						
				EGS					Hydrothermal	
				Binary			Flash		Binary	Flash
				100–125	125–160	160–220	220–300	300+	100–220	220+
1	Resources <$0.10/kWh	Reference	30,000	4.2	1.02	0.8	2.8	1.9	0.04	0.04
2	Resources <$0.15/kWh	Reference	58,000	4.2	1.02	0.8	2.8	1.9	0.04	0.04
3	NEMS-GPRA 2030	Reference	12,000	4.2	1.02	0.8	2.8	1.9	0.04	0.04
4	EIA 2035	Reference	3,900	4.2	1.02	0.8	2.8	1.9	0.04	0.04
5	Resources <$0.10/kWh	Improved	30,000	0.92	0.3	0.23	2.18	1.57	0.04	0.04
6	NEMS-GPRA 2030	Improved	12,000	0.92	0.3	0.23	2.18	1.57	0.04	0.04

U.S. Geological Survey (USGS) hydrologic unit code (HUC) 4 hydrological basins. This unit of analysis was selected to allow direct comparison with water availability data.

The water demand estimates from scenarios 1 and 3 were also compared with water availability estimates generated by Sandia National Laboratories to better understand the degree to which the incremental water demand from new geothermal generation is likely to stress each basin. The water availability dataset estimates water that is likely to be available for energy development based upon five different categories: (1) unappropriated surface water, (2) appropriated surface water, (3) potable groundwater, (4) shallow brackish groundwater, and (5) municipal wastewater (Tidwell 2012). For the purposes of this analysis, all five categories of water were included in the water availability used for comparison with estimated future water demand growth for geothermal development.

3.2 RESULTS

Estimated water demand was mapped for each of the six scenarios and is shown in Figures 4 and 5. Figure 4 illustrates water demand for the four scenarios based upon the LCA results for the GTO Reference scenarios. Scenarios 1 and 2 represent a longer term view and represent the majority of the known resources that will be considered for development over the medium and long term depending upon the price of electricity. It is unlikely that all of these resources will actually be developed, although many of them will be. Scenario 3 represents an optimistic growth scenario for geothermal over the next 20 years assuming continued investment and technological advancement. Scenario 4 represents a more conservative, status quo growth scenario based upon the 2012 EIA projections of 3.9 GW of new generation by 2035 (EIA 2012). These projections, however, continue to increase with each new estimate. The 2013 EIA projections now project more than 5 GW of new capacity by 2040 (EIA 2013). With this in mind, the general conclusion that can be drawn from these maps is that over the next 20 to 30 years, the incremental water demand from geothermal is likely to be manageable in most basins with the possible exception of the Imperial Valley in California. However, if geothermal technology, especially EGS, continues to improve and become less expensive, and the resource base becomes more fully exploited, water conflicts are likely to grow significantly. These conflicts could also be exacerbated if climate change results in reduced water availability in the region in the future.

These potential conflicts, however, may be at least partially mitigated if technological improvements also lead to lower life cycle water consumption. Figure 5 illustrates water demand for the four scenarios based upon the results for the GTO Improved scenarios. The biggest difference between the Reference and Improved scenarios is the change in assumptions about belowground water losses, from 5% for the Reference scenarios to 1% for the Improved scenarios. This leads to a moderate reduction in water consumption for scenarios 5 and 6 relative to scenarios 1 and 3, which are similar except for the water consumption factors. However, these scenarios include a number of EGS flash systems, which are still large water consumers because of their high aboveground water consumption. In scenario 6, EGS flash resources represent only 14% of generation but 52% of total water consumption. If some of these higher temperature resources (250 to 350°C) can be exploited utilizing binary technology, this would greatly reduce overall water consumption.

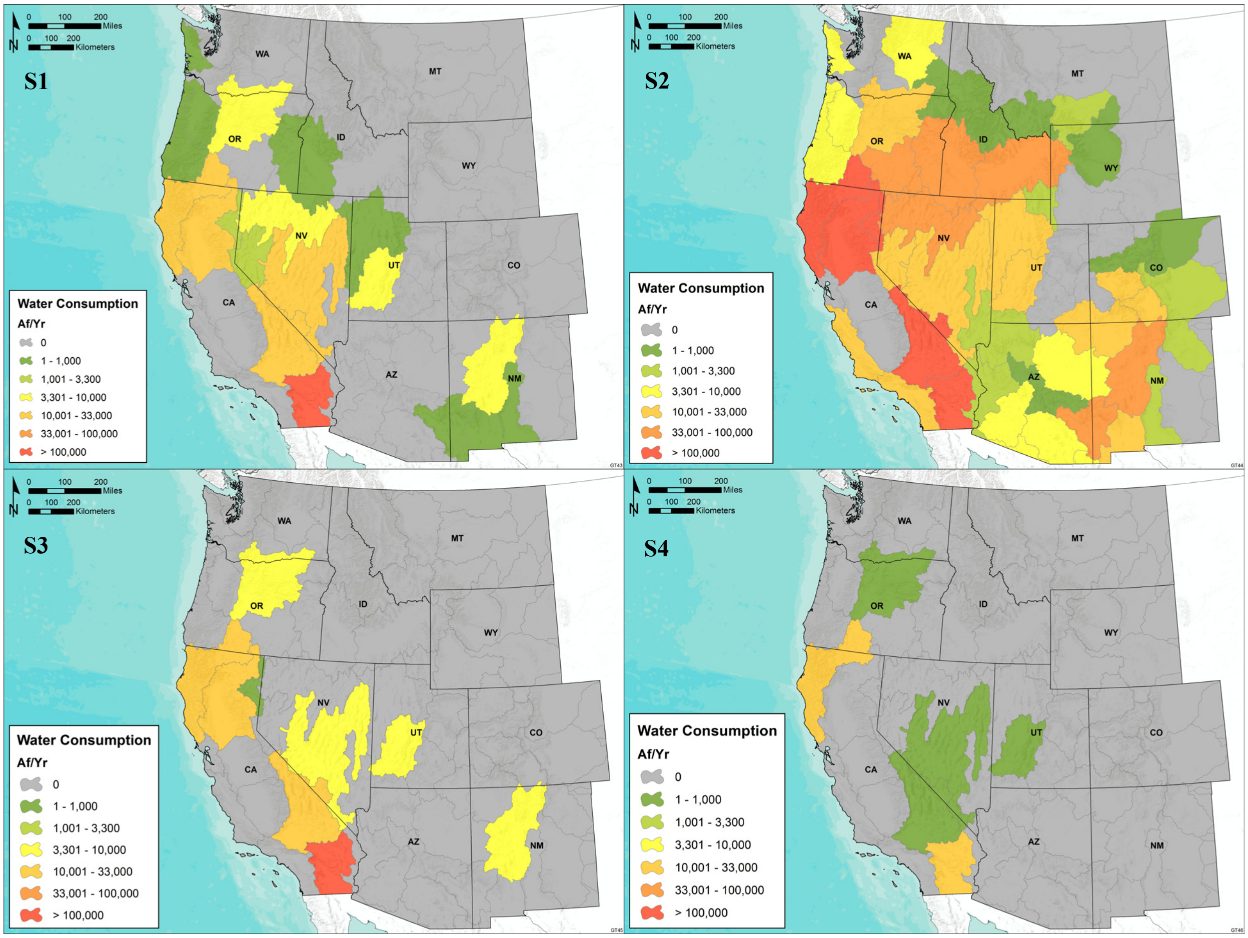

FIGURE 4 Regional Water Resource Assessment Water Demand Maps: Scenario 1 (top left), Scenario 2 (top right), Scenario 3 (bottom left), Scenario 4 (bottom right)

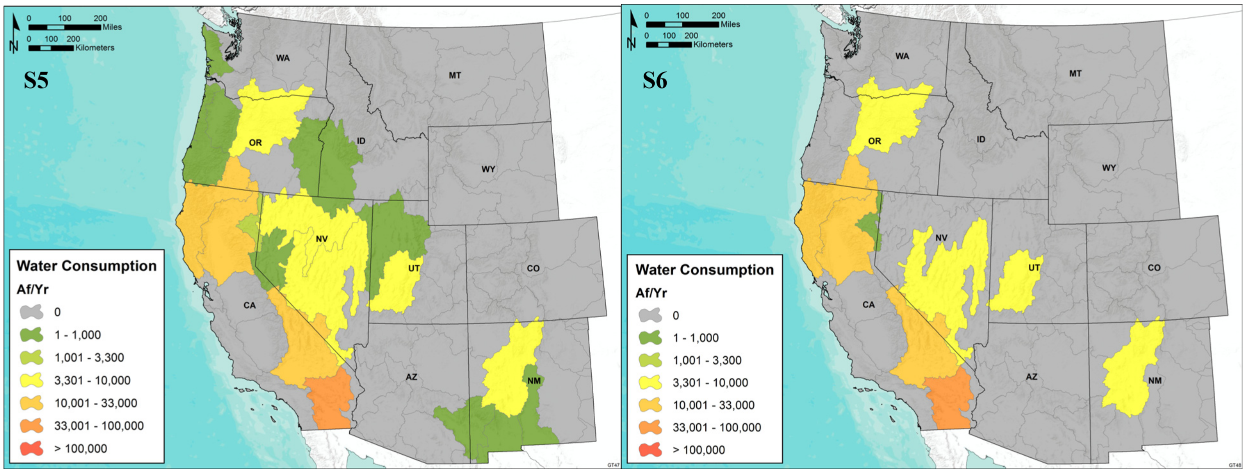

FIGURE 5 Regional Water Resource Assessment Water Demand Maps: Scenario 5 (left), Scenario 6 (right)

The water demand estimates from scenarios 1 and 3 were compared with estimates of total water availability for the same basins to estimate water stress and are illustrated in Figure 6. Although most basins show relatively low water stress, in both scenarios, the estimated water demand exceeds the likely water availability in the Imperial Valley, which indicates that future geothermal growth there has a high potential of becoming water constrained or at least having to displace other water users. A few other basins in California, Nevada, and Utah also show moderate potential for water stress, especially if water demand from other water users in these basins also increases.

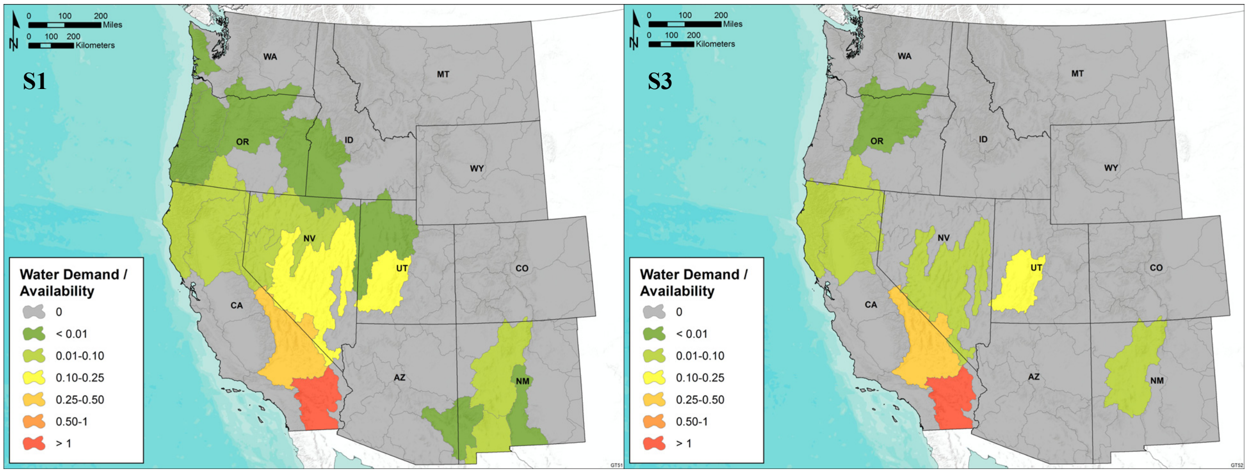

FIGURE 6 Water Stress Maps: Scenario 1 (left), Scenario 3 (right)

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4 LEGAL WATER DEFINITION REVIEW

Because our analysis of life cycle water consumption focused on freshwater consumption, an effort was made to distinguish and review applicable definitions of water, groundwater, and geothermal waters (or “geofluids”). The goal was to understand how these terms are defined by western states with existing geothermal power production, and how states and agencies use them for reporting requirements as they pertain to the development of geothermal power plants. To this end, a comprehensive legal and literature search was conducted on the terms “geofluid” and “geothermal waters.” Relevant cases and laws were researched further. Finally, a state-by-state legal and statutory review for water definitions for western states was also conducted, which included Arizona, California, Idaho, Nevada, New Mexico, Oregon, and Utah. The review specifically targeted how geothermal waters were managed at the state level, including whether or not the resources were managed more as minerals, or more as water resources, as well as what the dividing line was between geothermal waters and normal surface and groundwater resources, if any.

4.1 LEGAL WATER DEFINITION REVIEW RESULTS

4.1.1 Water in the Western United States

In the western United States, water is generally managed under the doctrine of Prior Appropriation, otherwise known as the law of “first in time, first in right.” This simplistic description belies a very complicated historical set of laws and policies, stretching back in time to when the West was settled, that serve to reward the first user of a water source who uses the water “beneficially.” What determines a beneficial use varies from state to state, but this policy has historically promoted actual removal of water and disincentivized in-stream uses, such as those for ecological protection, though several states have shifted in recent years and now include in-stream uses as beneficial use. If total flows are inadequate to service all claims on a specific source, claims are serviced in terms of seniority. This system stands in contrast to the management system used in the eastern United States, the Riparian Doctrine, inherited from England, which grants usage rights of water to those who have adjoining property rights to the source.

An old water law case from 1935, *State v. Hiber,* quotes the 1912 *A Treatise on the Law of Irrigation and Water Rights* by Clesson Kinney, which is generally accepted as the basis for the definition of the term “water” under Prior Appropriation. Water includes rivers and lakes but excludes most unconnected underground water, including even some hydrologically connected underground water, as well as rainwater and melting snow (diffuse sources) as they pass over the surface of the earth before they join rivers and lakes (though there are some western states that consider all water in this state to be a form of tributary to nearby rivers, and hence covered under the law) (Sax et al. 2006). Kinney says specifically, to be considered water, there must be, “…a channel, consisting of a well defined bed and banks, and a current of water…”(Kinney 1912).

This two-prong test is a helpful standard to return to when thinking about western water definitions.

It is worth noting that Prior Appropriation is the law of the land in all states with active geothermal energy projects with the exception of California. California follows a mixed system that combines appropriative rights with some riparian rights (Sax et al. 2006). In addition to appropriators, landowners above a water source also have claims on the water. Competing claims are required to be settled in court among all parties with a claim (Sax et al. 2006).

4.1.2 Groundwater in the Western United States

The range of potential uses for existing groundwater resources can be limited by the amount of salt found in it. Water that does not taste fresh (but is not as salty as seawater) is generally considered brackish. Many groundwater resources contain brackish water. While there is no exact definition for brackish water, the National Ground Water Association (NGWA) loosely defines it as “distastefully salty but less saline than seawater (between 1,000 to 10,000 ppm [parts per million] in total dissolved solids [TDS])” (2010). The NGWA also defines more specific categories of saline water, as shown in Table 6.

Groundwater has traditionally been treated separately from surface water. This is because historically, the science behind groundwater was not well understood, and so as a resource, it was ill defined and less emphasis was placed on it from a legal perspective (Sax et al. 2006). In addition, many jurisdictions adopted groundwater management policies well before there was high demand for groundwater development and before the invention of the centrifugal pump (Sax et al. 2006). As advances have been made in the science of hydrogeology, the law has been slow to catch up.

4.1.2.1 Federal-Level Groundwater Classification

The U.S. Environmental Protection Agency (EPA) classifies groundwater by its potential use as drinking water. There are three categories. Class I Special Groundwater is defined as groundwater of “unusually high value.” This water is highly vulnerable to contamination and is an irreplaceable drinking water source and/or ecologically vital (EPA 1986).

TABLE 6 Categories of Saline Water

Category	Salt Content (ppm)
Freshwater	Less than 1,000
Slightly saline water	1,000–3,000
Moderately saline water	3,000–10,000
Highly saline water	10,000–35,000
Ocean water	35,000

Class II groundwater is currently and/or potentially a source of drinking water. Any groundwater that could be a source of drinking water and is not considered Class I is included in this class, regardless of its potential for contamination.

Class III groundwater is not a potential source of drinking water and is of limited beneficial use. This water is either too saline for beneficial use (defined as TDS; concentrations above 10,000 mg/L) or too contaminated by natural conditions or broad-scale human activity to be cleaned up using reasonable treatment methods (EPA 1986). The U.S. Bureau of Land Management (BLM) also generally classifies water as usable if it contains TDS levels below 10,000 ppm.

As a means of establishing a spatial limit to groundwater classification, the EPA also defines groundwater units based on the type of boundaries between underground water resources to define the degree of interconnection between units.

4.1.2.2 State-Level Groundwater Classification

To make matters more complicated, early on, common law also distinguished between groundwater that flows in “underground streams” and groundwater that “percolates,” a distinction which several states, most notably California, still embrace. Subsurface streams were generally regulated under the same laws as surface waters because they “flowed” like surface waters, while a separate set of laws was developed for percolating groundwater (Sax et al. 2006). In addition, many statutes in western states exempt certain activities from groundwater laws. For example, mine dewatering and water recovered in mineral extraction activities, although technically groundwater, is exempted from that management system in states like Nevada, where it is effectively treated as surface water when it gets aboveground (Sax et al. 2006). Finally, some states also exclude groundwater of a certain temperature. For example, Idaho created a dual management system in which high-temperature groundwater resources are considered geothermal waters, while low-temperature resources are covered under normal groundwater laws (IS 2014). The recent trend in creating state-level groundwater management basins that trump common law management techniques further complicates the process of defining groundwater, as it can change quickly over a relatively small area and also potentially cross state borders. Whether or not geofluids are considered groundwater is another murky area discussed below.

Currently, groundwater is still generally defined separately from surface water and managed under one or a combination of five distinct management regimes applicable in the United States. In the western United States, the most prevalent system is the Prior Appropriation Doctrine as applied to groundwater. The first version of this was adopted by statute in New Mexico in the late 1920s and shortly after in Idaho (Sax et al. 2006). Utah, Washington, Nevada, Oregon, and Wyoming are all also credited with following this management scheme now as well (Sax et al. 2006). The Prior Appropriation Doctrine for groundwater shares many of the same characteristics as the surface water management technique described above. Namely, appropriation has a location, a date, a quantity, and must be used beneficially.

The Correlative Rights Doctrine, invented in California and in use there today, requires, "a sharing of available water on an equitable basis among overlying landowners who are using water on their overlying tracts" (Sax et al. 2006). Off-tract uses are subordinate and only permissible if there is surplus water available (Sax et al. 2006). Therefore, in California, for example, groundwater can only be exported off the land if there is no negative impact on others.

4.1.3 Geothermal Waters in the Western United States

Geothermal waters, or "geofluids," are a category of thermal groundwater with sufficient thermal energy to be used for geothermal energy production. How they are managed varies substantially across federal and state levels.

4.1.3.1 Federal-Level Geothermal Water Management

In an attempt to facilitate the development of geothermal energy projects on federal land, Congress passed the Geothermal Steam Act of 1970. This is the primary federal law related to geothermal resource development in the United States. While meant to clarify and simplify the leasing process, it actually complicated things in one key way: it left unresolved whether or not geothermal resources were included in reservations of mineral rights or whether they constituted water resources (Allen 1972).

A history of court cases clarified the intent of the law somewhat. In *United States v. Union Oil Company*, the Ninth Circuit Court of Appeals determined that mineral reservations in the Stock-Raising Homestead Act of 1916 were *intended* to include geothermal resources (Stoel Rives LLP 2009). Therefore, it effectively determined that under federal law, "geopressured geothermal resources fall within the category of Leasing Act minerals for the purpose of federal leasing programs established for natural resource development" (Callison 2010). Later, in the 2002 case *Rosette v. United States,* the Tenth Circuit Court of Appeals held a similar precedent, deciding that on land patented under the Stock Raising Homestead Act, the use of warm water to heat greenhouses, "constituted use of federally reserved geothermal resources and was therefore subject to federal leasing requirements" (Callison 2010). In other words, the federal government reserved geothermal resources for its own use, as they were not explicitly needed for the purpose of the Act as passed by Congress.

Much later, under the BLM's Programmatic Environmental Impact Statement for the federal geothermal leasing program, it states that, "The geothermal lease is for the heat in the federal mineral estate (DOI 2008). Unless specifically owned in fee, the fluid part of the resource falls under state water laws" (Callison 2010; DOI 2008). This in itself contradicts the federal definition of geothermal resource from 43 CFR 3200.1, which includes both heat and water and defines *geothermal steam and associated geothermal resources* as, "(1) All products of geothermal processes, including indigenous steam, hot water, and hot brines; (2) Steam and other gases, hot water, and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formations; (3) Heat or other associated energy found in geothermal formations; and (4) Any byproducts" (CFR 2014). More than 90% of geothermal energy production occurs on federal land, making this confusion especially problematic (Stoel Rives LLP 2009).

4.1.3.2 State-Level Geothermal Water Management

The Geothermal Steam Act's confusion between water and minerals also influenced state-level policy. This confusion creates uncertainty for geothermal developers because ownership of a water right may or may not also entail the right to develop geothermal resources (Stoel Rives LLP 2009). Management at the state level is thus going to come down to whether the state classifies geothermal resources under legal doctrines that govern groundwater appropriation, whether they classify the resources according to oil, gas, and mineral principles, or whether they use a hybrid system (Stoel Rives LLP 2009). Below, policies and definitions are explored on a state-by-state basis for western states with active geothermal energy development, thereby giving insight into how such categorization of geofluids can shape regulatory requirements as they pertain to geothermal energy development activities. Table 7 provides a brief summary of these management doctrines from a selection of states with active geothermal development in advanced stages (GEA 2014).

Arizona

Arizona law exempts geothermal energy development and related activities from state water law unless, "(1) such resources are commingled with surface waters or groundwaters of the state, (2) such development causes impairment of or damage to the groundwater supply; and (3) well drilling to obtain and use groundwater is subject to the water laws of the state" (ARS 2014; Callison 2010). In essence, geothermal resources are not considered water resources unless their development affects water resources in some way.

California

California's long-standing historical distinction between percolating waters and subterranean streams, coupled with the state's reliance on Correlative Rights rather than Prior Appropriation for its groundwater management, make this state an interesting case. Currently, geothermal resources are considered part of the mineral estate and permitted through the Division of Oil, Gas, and Geothermal Resources (BLM and USFS 2009). In addition, like some other states explored here, California also uses a bifurcated system to define what constitutes a geothermal resource and what constitutes traditional groundwater. For California, this line is the boiling point of the resource at the surface elevation of the resource when it comes out of the ground (CA PRC 2014). Finally, because of the use of the Correlative Rights Doctrine in California and because geothermal resources are considered a mineral, property rights are key (Stoel Rives LLP 2009). A developer's ability to use the geothermal resources beneath its land is limited to "a reasonable and proportionate share" based on the acreage of surface ownership compared with its neighbor's share of the same resource (Stoel Rives LLP 2009).

TABLE 7 State-Level Geothermal Water Management Definitions, Laws, and Principles

State	*Geothermal Water Water or Mineral?*	*Temperature Divide between Water and Geothermal Water (if applicable)*	*Relevant State Statutes*	*Groundwater Management System*
Arizona	Geothermal resources not considered water unless development creates water impacts	NA[a]	*Arizona Revised Statutes* (ARS) Chapter 4, Article 4, Sections 27-651.6 and 27-667	Prior Appropriation
California	Mineral	Boiling point at the surface elevation of the resource when it comes out of the ground (Example: The Geysers sits at ~2,400 ft, where water has a boiling point of 97.6°C, or 207.7°F)	*California Public Resources Code*, Division 3, Chapter 4, Sections 3701 and 3703.1	Correlative Rights
Idaho	Neither a mineral nor water *(sui generis*), though managed under the Department of Water	Resource temperature of 212°F (or 100°C)	Idaho Geothermal Resources Act in *Idaho Statutes* 42-4002(c)	Prior Appropriation
Nevada	Defined as a mineral but managed as a water resource by the Department of Minerals	NA	*Nevada Revised Statutes* (NRS) 534A.010	Prior Appropriation
New Mexico	Mineral and Water	Above 250º F, the resource is classified as a mineral. At or below 250º F, it is classified as water	*New Mexico Administrative Code* (NMAC), 19.14.1.7(o) and 19.14.1.7(r)	Prior Appropriation
Oregon	Mineral and Water	Above 250º F, the resource is classified as a mineral. At or below 250º F, it is classified as water	*Oregon Revised Statutes* (ORS), Sections 522.005.11 and 522.019.2	Prior Appropriation
Utah	Geothermal fluids classified as groundwater, though managed similar to minerals	Resource temperature of 120°C (or 248°F)	Utah Geothermal Resource Conservation Act in *Utah Code*, Title 73, Chapter 22, Sections 3 and 4	Prior Appropriation

[a] NA = not applicable.

Idaho

Idaho's Geothermal Resources Act includes a specific reference to water but goes on to state that "Geothermal resources are found and hereby declared to be sui generis, being *neither* [emphasis added] a mineral resource nor a water resource, but they are also found and hereby declared to be closely related to and possibly affecting and affected by water and mineral resources in many instances" (IS 2014). In reality, the Act bifurcates the resource into high- and low-temperature categories (with 212°F being the dividing line), but it actually regulates development under the groundwater Prior Appropriation Doctrine, with geothermal permitting governed by the Department of Water Resources (IS 2014; Stoel Rives LLP 2009). Developers must submit permit applications for both groundwater appropriation and a geothermal well permit in any case in which the development will decrease or impact the groundwater for prior water rights (Stoel Rives LLP 2009).

Nevada

In contrast to Idaho's explicit usage of water in defining geothermal resources, Nevada's geothermal statute simply mentions a transfer medium. It defines "geothermal resource" as "the natural heat of the earth and the energy associated with that natural heat, pressure, and all dissolved or entrained minerals that may be obtained from the medium used to transfer the heat" (NRS 2014). Despite the lack of 'water' in the definition, Nevada state law requires that water brought to the surface during geothermal energy production activities be subject to the Prior Appropriation Doctrine, unless it is subsequently reinjected in the same amount; that is, that no losses are encountered (Callison 2010). So while geothermal resources are not defined as water, their development is managed as such. However, the management authority responsible for geothermal energy development is the Division of Minerals, further confusing the situation. Although geothermal well drilling is also under the jurisdiction of the Nevada State Engineer, who is in charge of groundwater, the State Engineer has authority to waive appropriation permitting requirements for geothermal energy exploration (Stoel Rives LLP 2009).

New Mexico

New Mexico uses a bifurcated temperature classification system. High-temperature geothermal resources (those greater than 250º F) are permitted and managed as a "Mineral" under the Oil Conservation Division of the state's Energy Minerals and Natural Resources Department (EMNRD). At less than or equal to 250º F, the resource is classified as "Water" and is under the jurisdiction of the Office of the State Engineer of New Mexico (NM EMNRD 2014; BLM and USFS 2009).

Oregon

Oregon's geothermal resource management system provides an example of how defining the resource differently across multiple state agencies can create the potential for regulatory confusion (Stoel Rives LLP 2009). In Oregon, geothermal resources with a bottom hole temperature of 250°F and above are regulated as minerals by the Department of Geology and Mineral Industries (DOGAMI), while those with a bottom hole temperature of less than 250°F are considered groundwater resources, administered by the state Water Resources Department, with each agency having its own separate permitting requirements and administrative system (ORS 2014; BLM and USFS 2009). Further complicating matters, Oregon also separately defines high-temperature geothermal resources not only by temperature but, alternatively, by depth of the well. Any well deeper than 2,000 ft can potentially be considered a geothermal well, and regulated as such (ORS 2014; Stoel Rives LLP 2009).

In terms of distinguishing between groundwater and geothermal resources, Oregon also uses an intent-based standard to distinguish among water supply wells, low-temperature geothermal wells, which are "constructed or used for the thermal characteristics of the fluid contained within," and geothermal wells, which are "drilled to explore for or produce geothermal resources from any depth" (OAR 2014; Stoel Rives LLP 2009). This system inevitably creates confusion and the ability for a well to be regulated by both DOGAMI and the Water Resources Department. Oregon stipulates that agencies should work together to help developers navigate these various requirements (Stoel Rives LLP 2009).

Utah

Utah treats geothermal fluids as a special kind of underground water resource. Although Utah state law defines geothermal resources as those with temperatures of at least 120°C, the state classifies geothermal fluids as groundwater (UC 2014a; Stoel Rives LLP 2009). As far as the administrative system for geothermal resources, although the State Engineer, who normally administers groundwater, is also responsible for geothermal resource development, the management techniques he/she uses are very similar to guidelines in place in the Division of Oil, Gas, and Mining (Stoel Rives LLP 2009). In particular, under Utah law, management of a geothermal resource derives from interest in the land, that is, a property right, and not from a right to the fluids under Prior Appropriation Doctrine, making the system a hybrid of both mineral and water resources (UC 2014b; Stoel Rives LLP 2009). In addition, and to further complicate things, Utah has passed statutes that affirm the state's historical dependence on the Correlative Rights Doctrine, like California, even though the state no longer strictly practices the Doctrine (Stoel Rives LLP 2009).

5 SUMMARY AND CONCLUSIONS

The geothermal water life cycle scenarios have been updated to be consistent with the current LCOE scenarios used by GTO. These scenarios include a more complete exploration of the parameter space of possible geothermal power plants and allow for a more thorough examination of the impact of key factors on life cycle water consumption. The most important of these factors was shown to be resource temperature. In general, higher resource temperatures result in lower water consumption for the same technology; however, going from binary systems that typically operate at lower temperatures to flash systems that operate at higher temperatures results in a large jump in the aboveground operational loss of geofluid. In most hydrothermal systems, this additional loss of geofluid is not replaced, which does not increase water consumption, but it does have long-term impacts on the sustainability of the reservoir. However, in EGSs this lost geofluid will more than likely need to be replaced to maintain reservoir pressure. The use of alternative, lower quality water sources will be important in these cases because of the high water requirements relative to competing electricity generation systems. Another option for reducing water impacts would be the use of binary systems for higher temperature EGS resources than are traditionally usually used for hydrothermal resources. This option is likely to be most viable for geothermal resources more than 200°C but lower than 300°C.

The regional water resource assessment was also updated to include the new LCA numbers and to provide a direct comparison with water availability metrics. The general conclusions from this analysis are that over the next 20 to 30 years, the incremental water demand from geothermal development is likely to be manageable in most basins with the possible exception of the Imperial Valley in California. However, if over the years geothermal technology, especially EGS, continues to improve and become less expensive, and the resource base becomes more fully exploited, water conflicts are likely to grow significantly. These conflicts could also be exacerbated if climate change results in reduced water availability in the region in the future. Some of these conflicts can be at least partially mitigated if technological improvements can also help to minimize belowground water losses and/or allow for greater use of lower quality water sources such as brackish or saline groundwater.

From a policy perspective, for geothermal to be more competitive with other renewable technologies, the uncertainty regarding what constitutes a geothermal resource, and thus the variability of these definitions from state to state, should be addressed. In addition, how this resource should/can be exploited, including establishing definitively who the primary regulator is, should also be clarified. Some solutions to this issue are already being implemented. Most notably, DOE's Geothermal Regulatory Roadmap (GRR) initiative (http://en.openei.org/wiki/GRR) attempts to streamline the geothermal permitting process for developers by identifying state and federal agencies involved in the development process, estimating timelines for different stages of the process, and identifying potential areas of overlap and concern. Improving communication across stakeholders can better inform the process and facilitate understanding of the various definitions of geothermal resources and water resources. This would ultimately help enable the development of geothermal resources and secure the sustainability of these resources through the acquisition of the most appropriate type of water for specific stages of geothermal development and operations.

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