PROCEEDINGS, Thirty-Eighth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 11-13, 2013
SGP-TR-198

GEOTHERMAL ENERGY: THE ENERGY-WATER NEXUS

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ABSTRACT

Building upon a life cycle assessment (LCA) of geothermal systems, this paper examines the energy-water interactions and potential challenges faced by a growing geothermal industry. A process LCA approach was used to estimate water consumption for a range of geothermal plant designs. The life cycle water consumption values were then used to explore geothermal growth scenarios to estimate potential regional water demands for new geothermal development. These water demands were then compared with metrics for water availability to identify areas where water related challenges are most likely to occur.

INTRODUCTION

Water consumption is known to occur at four main stages along the development of geothermal power plant. Water is required for constructing all geothermal power plants, especially in the drilling of production and injection wells. Water is also used above ground in the ongoing operations of geothermal power plants for cooling in wet and hybrid cooled systems and for other non-cooling uses such as dust suppression, cleaning, maintenance, and domestic needs in all systems. Enhanced geothermal systems require additional water for stimulation and flow testing of engineered reservoirs. In addition EGS systems have a tendency to lose water slowly to the surrounding formation which must be replaced through supplementary water injection to maintain system performance.

This work builds upon previous work examining life cycle water consumption for various geothermal technologies to better estimate water consumption across the life cycle for these technologies and to assess the potential water challenges that future geothermal power generation projects may face (Clark et al. 2011, Clark et al. 2012). It is divided into two parts. The objective of the first part was to examine past and existing geothermal projects to improve estimates of water consumption for various stages of the geothermal life cycle. The results of which informed a life cycle analysis (LCA) of water consumption. The life cycle water consumption results were then integrated with potential geothermal growth scenarios in part two. The objective of the second part was to examine water consumption by geothermal projects at a regional scale. The future water demand for various scenarios were compared with metrics for water availability to identify potential water challenges that projects may face in areas where water scarcity is already a concern.

METHODOLOGY

The study was broken into two primary parts. The first part included a water LCA that estimated with water life cycle water consumption for three different power plant scenarios. The second part evaluated the regional water implications of growth in geothermal development.

For the purposes of this paper water consumption is defined as freshwater that is withdrawn from a ground or surface water source and not returned. Water consumption occurs through evaporation (cooling water), incorporation into materials (cement or drilling muds), or lost to the subsurface (drilling or stimulation). The use of consumption of geofluid – the fluid produced from the geothermal reservoir to produce power is not considered water consumption for the purposes of this study.

Water Consumption LCA

A process-based LCA was conducted to account for freshwater consumption and considered activities associated with drilling, stimulation, construction, and operating the wells and the power plant. Three power plant scenarios were considered with input from experts in industry and other national

Table 1: Geothermal Technology Power Plant Scenarios

Parameters	Scenario 1	Scenario 2	Scenario 3
Geothermal technology	EGS	Hydrothermal	Hydrothermal
Net power output (MW)	50	10	50
Producer-to-injector ratio	2:01	3:1 and 2:1	3:1 and 2:1
Number of turbines	Multiple	Single	Multiple
Generator type	Binary	Binary	Flash
Cooling	Air	Air	Evaporative
Temperature (°C)	150–225	150–185	175–300
Thermal drawdown (%/yr)	0.3	0.4–0.5	0.4–0.5
Well replacement	1	1	1
Exploration wells	1 or 2	1	1
Well depth (km)	4–6	<2	1.5, <3
Flow rate per well (kg/s)	30–90	60–120	40–100
Gas/brine ratio (scf/stb)	NA	NA	NA
Pumps for production	Submersible 10,000 ft	Lineshaft or submersible	None
Distance between wells (m)	600–1,000	800–1,600	800–1,600
Location of plant in relation to wells	Central	Central	Central
Plant lifetime (yr)	30	30	30

[a]NA = not applicable.

laboratories as shown in Table 1. The scenarios included one hydrothermal flash, one hydrothermal binary and one EGS power plant. The scenarios were modeled in the DOE's Geothermal Electricity Technology Evaluation Model (GETEM) to estimate important system parameters (DOE 2011a). These system parameters were then used to help estimate the water consumption for each stage of the geothermal life cycle based upon an extensive literature review. The review included not only the academic literature but also environmental permitting reports and state agency permits and data. This work focused on improving previous estimates for consumption in the EGS and hydrothermal scenarios in each critical stage of the life cycle (Clark et al. 2011, Clark et al. 2012).

Water Resource Assessment

The regional water resource assessment builds upon previous work exploring the geospatial distribution of water demand for future geothermal power production (Clark et al. 2012). The current analysis makes four key improvements upon the previous analysis: (1) increases the spatial resolution of the analysis, (2) updates the water consumption factors based upon the water LCA results presented in this paper, (3) adds additional growth scenarios, and (4) includes metrics on water availability. The spatial resolution of the analsysis is local watersheds was defined by the four digit US Geological Survey hydrologic unit codes (HUC 4). The use of USGS HUC 4 basins as a unit of analysis allowed for direct comparison with water demand and availability data which are often presented on the basis of hydrological basins.

The regional water resource assessment combines the LCA results presented with a detailed supply curve for geothermal resources developed by NREL (Augustine et al. 2010). On the basis of what was known about the resources, NREL used GETEM (DOE 2011a) to model the electricity generation capacity (MWe) and estimate the levelized cost of electricity (LCOE, $/kWh). LCOE was estimated using two sets of cost assumptions: (1) a "base" case based upon current costs with minimal technological improvements, and (2) a "target" case that assumed a reduction in cost over time for EGS systems 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 are used in this analysis and are referred to as "base" and "target" throughout.

Within the geothermal supply curve, geothermal resources are broken down into four resource categories: identified hydrothermal, unidentified hydrothermal, near-field enhanced geothermal systems (EGS), and deep EGS. Identified hydrothermal resources are resources known to exist and capable of supporting hydrothermal geothermal power systems. Unidentified hydrothermal resources are resources that are likely to exist based upon heat flow maps and surface manifestations but have not been verified. Near-field EGS resources are associated with identified hydrothermal resources but may require additional stimulation to be exploited. Deep EGS resources are hot rock formations found at depths greater than 4 km and require stimulation to create fractures for fluid circulation for power generation.

The resolution of location information available within the NREL supply curve data set for the geothermal resources varied depending upon the resource type. For identified hydrothermal and near-field EGS resources, specific latitude and longitude locations are given. Unidentified hydrothermal resources are specified at the state level. Deep EGS resources are specified by temperature and depth along the region code for both the National Energy Modeling System (NEMS) model. These region codes cover many states. In order to perform analysis based upon USGS HUC 4 basins, the unidentified hydrothermal and deep EGS resources were interpolated to increase the spatial resolution using temperature at depth maps developed by Idaho National Laboratory and Southern Methodist University (INL 2011).

Both the unidentified hydrothermal and deep EGS resources were defined in the supply curve by a temperature and depth range for a given state or NEMS region code. The total area within the specified state or NEMS region was calculated where the temperature was within the specified range from the temperature data for the specified depth for each resource defined within the supply curve. These areas were then apportioned to the overlying HUC 4 basins. The generation capacity for the resource was then allocated to these HUC 4 basins in direct proportion to the calculated resource areas. Temperature data was available for depths of 3km, 4km, 5km, 6km, and 10km. For depths between 6km and 10km, and below 3km, temperatures were interpolated or extrapolated based upon trends calculated from the existing data using a geo-spatial tool called a Raster Calculator.

Water consumption factors based upon the LCA results presented later in this paper were then applied to the resources within the supply curve depending upon system type (EGS, hydrothermal flash, hydrothermal binary). The resources selected from the supply curve for each scenario were selected based upon the estimated LCOE by selecting the lowest cost resources first until the total new geothermal capacity defined by the scenario was achieved. The scenarios were mapped utilizing GIS software to illustrate the spatial distribution of water demand from the various growth scenarios.

A total of four growth scenarios are presented based upon results from the Energy Information Administration's NEMS integrated energy model (EIA 2011). Two scenarios are based upon a version that was modified to include the existing NREL geothermal supply curve. This version of the NEMS model is referred to as NEMS-GPRA, for Government Performance and Results Act. The modeling was performed in 2010 by OnLocation, Inc., for the DOE Geothermal Technologies Program for its annual internal program analysis. The results, presented at the fiscal year 2010 4th-quarter meeting of the Geothermal Strategic Planning and Analysis Working Group (Wood and Dublin 2010), showed growth in geothermal electricity production of 7.9 GWe by 2030 for the base supply curve and 11.5 GWe for the target supply curve. A third scenario is based upon these same modeling results for the target supply curve but uses a lower water consumption factor for EGS systems. The basis for this lower consumption factor is the assumption that below ground operational losses for EGS systems are made-up utilizing non-fresh water sources, limiting the impact on fresh water resources. The forth scenario is based upon NEMS model results presented in the EIA's 2012 Annual Energy Outlook that show growth in geothermal electricity production of 3.9 GW by 2035 (EIA 2012).

In addition to estimating water demand, an attempt was made to quantify the availability of water at the same HUC 4 resolution. These estimates were based upon data provided by Sandia National Laboratory (Tidwell 2012). The data set is currently limited to thirteen Western states, but these states overlap with the majority of the geothermal resource in the continental US with the exception of some deep EGS resources.

Sandia also provided estimates of water availability divided into five different categories: unappropriated surface water, appropriated surface water, potable ground water, shallow brackish ground water, and municipal waste water. Unappropriated surface water availability was determined by comparing stream flow to downstream delivery requirements when specific estimates were not provided directly by the states. Appropriated surface water availability was estimated based upon the quantity of water consumed by low value agriculture (hay and alfalfa). A percentage of this water was assumed to be available for sale for higher value uses. Potable groundwater availability was calculated based upon the safe yield where pumping must be less than or equal to recharge rates based upon USGS data. Shallow brackish groundwater availability was estimated by aggregating data from multiple state and USGS data sets. Municipal waste water availability was estimated based upon discharge data from the USGS and EPA (Tidwell 2012). From these data two aggregate metrics were developed and mapped. A “total fresh water availability” metric was defined by combining the unappropriated surface water, appropriated surface water, and potable groundwater volumes. A “total water availability” metric was also defined by combining all five categories of water.

While no formal numerical analysis was performed comparing water demand for geothermal from the various scenarios with the included water availability metrics for this paper, a qualitative analysis is included which identifies some of the basins where the limited availability of water is most likely to impact the development of geothermal resources. More detailed quantitative comparison of water demand and availability along with a focus on the cost of different water resources will be a focus of ongoing research.

GEOTHERMAL WATER CONSUMPTION

Drilling and Construction

Water is consumed in the drilling of geothermal production and injection wells both in drilling muds and in the cement used to construct the wells. Water is also consumed in the concrete often used in support structures for pipelines that transport the geofluid from production wells and to injection wells and in the construction of the power plant itself.

The two approaches to estimating water volumes for drilling and constructing wells are the following: (1) estimates provided in the literature (BLM 1998; 1999; 2003; 2005; 2006a,b; 2007a,b; 2009; 2010a–e; 2011a–i; 2012) and (2) estimates based upon well designs as discussed in Clark et al. (2011). Estimates in the literature report consumption that is twice that of the well design estimates with at an average water consumption of 180,000 gallons per 1000 feet of well depth. The literature reported maximum projections of daily water volumes during the drilling period (e.g. Dixie Meadows EA, Patua EA, Soda Lake EA) and therefore are likely to be conservative estimates. For this reason the estimates according to well design were incorporated into the life cycle water analysis. Although data were collected for observation and exploration wells, the life cycle water consumption estimates were based upon total production and injection wells as the water burden of any exploration wells that do not become production or injection wells would likely be shared among plants developed within a geothermal area.

Water consumption for the development of the pipeline and the power plant were determined to be negligible per lifetime energy output in the previous analysis (Clark et al. 2011). As a result, no additional analysis was undertaken for this work, and the estimates from the previous report were maintained for the overall water consumption over the lifecycle.

Stimulation and Circulation Testing

After a well is drilled for an EGS project, it is typically stimulated. Stimulation may occur on a production or injection well. Stimulating a production well can enhance the output of the well by (1) improving near-well permeability that has been reduced by the drilling operation clogging pathways or (2) opening up paths to permeable zones not intersected by the well. For injection wells, stimulation similarly enhances the injectivity of the wells. Three general types of well stimulation are used in EGS development: thermal, hydraulic, and chemical stimulation. Thermal stimulation relies on the introduction of chilled water, and thus cold stress, to a geothermal reservoir. Hydraulic stimulation relies on the introduction of water or a combination of water and gel-proppant fluids to a geothermal reservoir. Chemical well stimulation techniques involve the use of aqueous solutions to allow acids, bases, and chelating agents to be introduced into geothermal reservoirs. Water is the primary additive for all well stimulation activities.

The amount of water required for well stimulation activities is dependent upon the well-reservoir environment and the well stimulation method(s) used. For EGS, stimulation can consume a significant quantity of water over a short period of time. The literature review found a range of 1,500,000 to 7,700,000 gallons required per well for stimulation (Zimmermann and Reinicke 2010; Asanuma et al. 2005; Tester et al. 2006; Häring et al. 2008a; Chen and Wyborn 2009; Evans et al. 2012; Portier et al. 2009; Xu et al. 2012; Michelet and Toksöz 2006; Cordon and Driscoll 2008; Schinler et al. 2010; Kitano et al. 2000; Shapiro et al. 2006a; Zoback and Harjes 1997). The average of 5,100,000 gallons was consistent with the 5,300,000 gal used in the previous analysis (Clark et al. 2011). For the scenarios examined, when amortized over the lifetime of a power plant, stimulation was found to consume a similar volume of water as drilling and cementing wells. This is due to the assumption that only injection wells would be stimulated, and that the ratio of production to injection wells is 2 to 1. For projects where these conditions are not met, consumption volumes may not be as comparable.

Surrounding the stimulation stage for EGS projects are a series of flow tests that require water. Accounting for pre-stimulation, post-stimulation, short-term circulation, and long-term circulation tests, the water consumed for circulation testing is similar to the volumes required for drilling and cementing and stimulating per lifetime energy output for the EGS scenarios (Tester et al. 2006). There is a great deal of uncertainty on the water volume required for long-term, commercial scale circulation testing. Projects to date have been small-scale, proof of concepts. As a result, circulation testing consumption estimates may change in the future as commercial scale projects are developed.

Above Ground Operations

The largest variable affecting above ground operational water consumption is the type of cooling system used. The current analysis focuses primarily on dry cooled binary systems and wet cooled flash systems that utilize condensed geofluid for cooling water. However, wet and hybrid cooled systems are also often used and are therefore discussed in this section. Cooling system selection is an important design criterion and affects not only lifetime water consumption, but also the power generation efficiency of the power plant. While dry cooling systems drastically reduce the water consumption for geothermal power plants, they also come at the cost of lost efficiency, especially on hot summer days when power is often the most valuable.

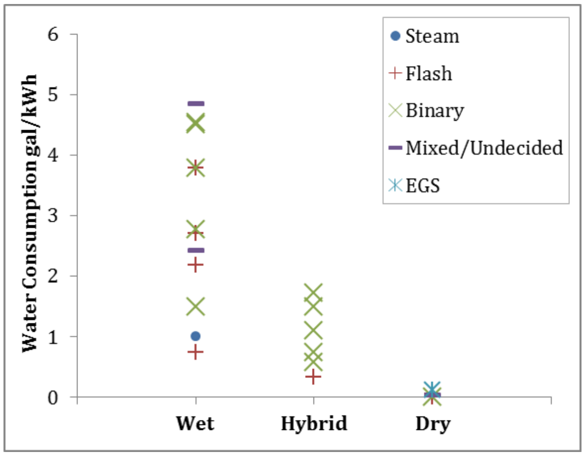

Figure 1: Geothermal Operational Water Consumption Data.

The data gathered from the more extensive literature review are presented in Figure 1 (BLM 2007b; 2010a,c; 2011a,g; BLM and US Navy 2008; Calpine 2012; DOE 2011b; EMA 2006; Geodynamics 2011; Kagel et al. 2005; Kozubal and Kutscher 2003; MHA 2008; NDWR 2012). The data are presented by cooling system type and identified by the type of power plant. In some cases data were provided as aggregate numbers from facilities that operate both flash and binary systems or were projections for proposed power plants where the determination to build a flash or binary system had not been finalized. Wet cooled flash plants ranged from 0.7 to 3.8 gal/kWh with an average of 2.4 gal/kWh. Water consumption from wet cooled binary plants was slightly higher, ranging from 1.5 to 4.6 gal/kWh with an average of 3.4 gal/kWh. This difference is likely attributed to two factors: flash plants operate with higher temperature geofluid which makes them more thermodynamically efficient and many of the data points for flash systems were based upon injection augmentation programs which may not account for 100% replacement of lost geofluid. Injection of make-up water into a geothermal reservoir to replace evaporated geofluid condensate used for cooling in flash plants is optional and does not occur at many flash plants. This is an operational decision that is based upon economics and the local availability of water. Injection can extend the life of the reservoir at the cost of significant water consumption. When supplemental injection is not practiced, non-geofluid operational water consumption is minimal and similar to that of dry cooled systems. Binary plants on the other hand are almost always operated as closed loop systems with all of the produced geofluid being directly reinjected and always require an external source of high quality water for cooling if a wet or hybrid cooling system is used.

Hybrid cooling systems combine air and wet cooling, relying on air cooling most of the year, but supplement with wet cooling in warmer weather. Hybrid cooling systems can increase the power output of a geothermal power plant in the summer when power prices are highest while requiring significantly less water than a wet cooled system. There are many different designs of hybrid cooling systems and the decision on when to operate them is ultimately an economic one; trading off the cost and impact of water consumption vs. the incremental increase in power production revenue depending upon the market and weather conditions (Kozubal and Kutscher 2003). Water consumption for hybrid cooling systems ranged from 0.3 to 1.7 gal/kWh. The average was 1.0 gal/kWh.

The operational water consumption for dry cooled systems is quite low compared to wet and hybrid cooled systems. There is no direct water consumption for dry cooling, however there can be water consumption for other operational activities including dust suppression, maintenance, and domestic needs. All data obtained for non-cooling related operational water consumption from all systems were used to estimate the operational water consumption from dry cooled systems. The data ranged from 0.001 to 0.12 gal/kWh. The average was 0.04 gal/kWh.

The hydrothermal binary and EGS LCA scenarios are based upon dry cooling systems. For these systems the average water consumption from the literature review was used for operational water consumption.
The flash scenario assumes wet cooling utilizing condensed geofluid for cooling. The scenario assumes a 30 year plant lifetime with no geofluid replacement. This results in a loss of geofluid that is not replaced and therefore is not included within the fresh water consumption total. The fact that geofluid is not replaced will ultimately reduce the lifetime of the reservoir. Determining when and if you should inject replacement fluid into the reservoir to extend its lifetime is a question that must be answered independently at each power plant based upon the economics and the local availability of water. At least three geothermal power plants have operated injection programs to supplement declining reservoirs (Geysers, Coso, and Dixie Valley).

Below Ground Operational Losses

Enhanced geothermal systems are unique from other geothermal systems in that they rely on artificially created reservoirs in formations that may not have sufficient fluid in place to economically generate power. Fluid, most often water, must be added to the reservoir and circulated between injection and production wells to generate power. The reservoir that is created is rarely completely isolated, and, over time, some portion of the introduced fluid is often "lost" to the surroundings. These losses must be made up by introducing additional fluid to maintain reservoir pressures, flow rates from production wells, and power output.

Operational loss belowground refers to water injected into the reservoir and not returned to the surface during steady-state operations. These losses are commonly calculated as the difference between average injection and production rates over a given period of steady-state operation. There are three mechanisms by which operational water is lost. Water may be permanently lost either by (1) pressure diffusion on the periphery of the reservoir or by (2) leakage through natural faults and fractures extending beyond the reservoir. Operational water loss can also occur through (3) expansion of the engineered reservoir—either through new fractures within the reservoir periphery or dilation of existing ones. Upon depressurization of the reservoir, some of the fracture dilation may be lost, and thus the operational water filling this space will return to the surface (Murphy et al. 1999).

Below ground losses for EGS are highly variable from formation to formation and difficult to predict a priori. Given that large flow rates of geofluid are required to operate geothermal power systems, even small percentage losses of fluid to the surrounding reservoir can add up to significant quantities of fluid over the lifetime of a power plant. Based upon the limited test data available in the literature, loss rates for viable projects will likely range from 1 to 10%. Loss rates above 10% will also probably occur, but it is unclear if those projects will be viable or will be considered failed projects and abandoned (Tester et al 2006; Mishra et al 2010; Evans et al. 2012; DeMeo and Galdo 1997; Murphy et al. 1999; Duchane and Brown 2005). The exact upper limit cutoff for EGS project viability is uncertain and likely to be location and project dependent. Reservoir losses should be considered among the many risks to project success when assessing any new EGS project. Improved understanding of what geological factors influence reservoir losses will be important to improve loss predictions and reduce project risk.

Given the high uncertainty associated with below ground operational water requirements the full range of feasible loss rates from 1 to 10% are considered for the EGS LCA scenarios. This gives a range of below ground operational water requirements from 0.18 to 1.8 gal/kWh. The midpoint of the range, 5%, was assumed as for the baseline resource assessment scenarios where a single value was required. It is important to note that while fresh water may be used for supplemental injection, the water does not necessarily have to be of high quality. The fluid that is used does however have to be chemically compatible with the formation. The most important factor when determining water quality requirements for injected fluid is likely to be concentrations of scale forming compounds. Concentrations of calcium are of particular importance since calcite solubility declines with increasing temperatures and can precipitate within the reservoir as the fluid is heated, potentially reducing injectivity of injection wells (Clark et al. 2011).

Water LCA Results

The water consumption estimates for each stage of the life cycle were combined and shown in Table 2. Even when stimulation and flow testing are included for EGS systems the water consumption from the plant construction stage is minimal when amortized over the lifetime of a power plant. Above ground operational water consumption for dry cooled

Table 2: Total Life Cycle Estimates for Various Geothermal Technologies in Gallons per Kilowatt-Hour[a]

Power Plant	Plant Construction	Plant Operations (aboveground)	Plant Operations (belowground)	Total Life Cycle
EGS	0.009[b]	0.04	0.18–1.8[c]	0.22–1.85
Hydrothermal Binary	0.001	0.04	0.04	0.04
Hydrothermal Flash	0.001	0.04 (2.7)	0.04 (2.7)	0.04 (2.7)

[a] Numbers in parentheses assume 100% replacement of lost geofluid.

[b] Includes stimulation and circulation testing.

[c] Accounts for 1 to 10% belowground operational water loss.

systems is also fairly low. However, the loss of geofluid for flash systems is quite significant. The decision to make up this fluid loss to improve reservoir sustainability would require quite a bit of water. Below ground operational losses for EGS systems can also become quite substantial depending upon the reservoir conditions. However, this water does not necessarily have to be of high quality and research efforts should be devoted to better understand the water quality requirements for water injected for make-up water or reservoir augmentation. The ability to utilize lower quality resources such as produced water, brackish groundwater, or other saline water sources could minimize the impact that these systems have on freshwater resources.

WATER RESOURCE ASSESSMENT

Water Demand

Water consumption estimates for the water demand scenarios were based upon the LCA results presented above. Identified or unidentified hydrothermal resources with a temperature above 225°C were treated as hydrothermal flash systems with freshwater consumption of 0.04 gal/kWh. Identified or unidentified hydrothermal resources with a temperature below 225°C were treated as hydrothermal binary systems with freshwater consumption also of 0.04 gal/kWh. All EGS resources, both near-field and deep EGS, were assumed to be from binary systems with a 5% belowground operational water loss leading to total water consumption of 0.95 gal/kWh. For this analysis, it was assumed that all belowground losses would be made up with freshwater. This is a conservative assumption as it may be possible to meet some or all of this water demand from nonpotable sources. To test this sensitivity, one of the scenarios was run assuming no freshwater use to make up for belowground water losses. In this scenario, a water consumption factor of 0.05 gal/kWh was used for EGS resources. All water consumption factors were applied to the resources in the supply curve assuming a 90% capacity factor based upon the estimated generation capacity potential for each resource. Table 3 shows the parameters and results for each of the four water demand scenarios.

Maps of all four scenarios are shown in Figure 2. The geographical distribution of the water demand is fairly similar in all four scenarios. In the NEMS-GPRA 2030 base cost curve scenario, the water demand remains low in nearly all basins due to the fact that EGS resources remain uneconomical in this scenario. Only one basin in southeastern California (HUC 1810) exceeds 1,000 acre-ft/yr, with water consumption of just over 5,000 acre-ft/yr. When the target cost curve was used instead, the water consumption for this basin jumped up to more than 50,000 acre-ft/yr while also increasing in all other basins. However, when nonpotable water was used for makeup of belowground operational water losses for EGSs, the water consumption dropped below 5,000 acre-ft/yr in all basins. The EIA Annual Energy Outlook 2035 target scenario resulted in only half the generation capacity of the NEMS-GPRA 2030 base scenario, and a third of the generation of the NEMS-GPRA 2030 target scenario, but still resulted in nontrivial water consumption for two basins in California. In Northern California, basin 1801 shows water consumption of 6,000 acre ft/yr due to the development of near-field EGS resources at the Geysers geothermal field. In southeastern California, basin 1801 shows water consumption of 14,000 acre-ft/yr due to the development of near-field EGS resources near the Salton Sea. While in all scenarios the total amount of water required is relatively low, many of the resources are located in areas where any water consumption can be challenging.

Water Availability

The water demand scenarios were compared with water availability data provided by Sandia National Laboratories as described in the methodology section.

Table 3: Summary of Water Demand Scenario Results

Scenario	New Geothermal Generation (MW)	Total Water Consumption (acre-ft/yr)	Average Water Intensity (gal/kWh)
NEMS-GPRA 2030 growth scenario, base cost curve	7,900	7,700	0.04
NEMS-GPRA 2030 growth scenario, target cost curve	11,500	87,000	0.31
NEMS-GPRA 2030 growth scenario, target cost curve, no EGS reservoir loss	11,500	13,000	0.05
EIA Annual Energy Outlook 2012 2035 growth scenario, target cost curve	3,900	24,000	0.26

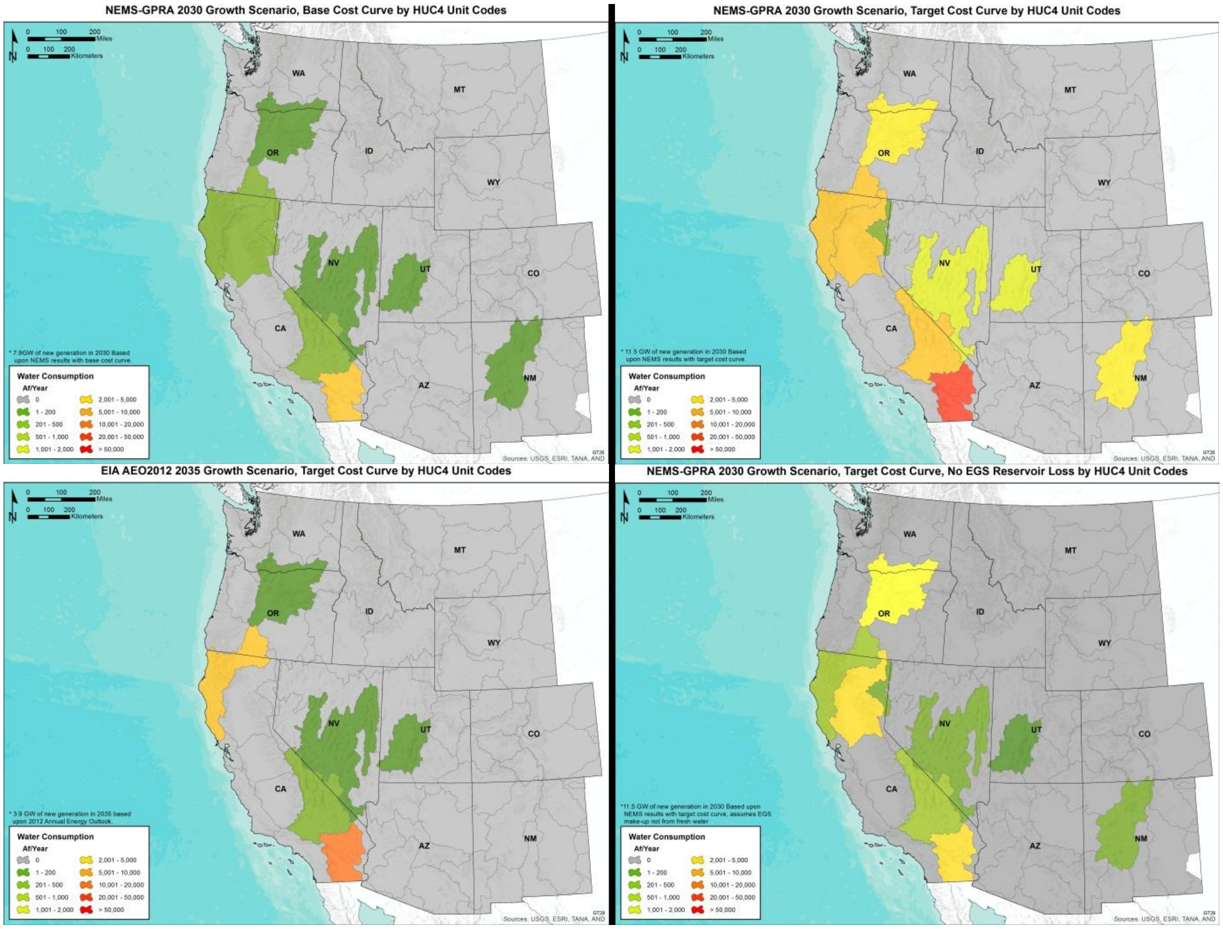

Figure 2: Water Consumption Scenarios: NEMS-GPRA 2030 Base Cost Curve (top left), NEMS-GPRA 2030 Target Cost Curve (top right), EIA Annual Energy Outlook 2035 Target Cost Curve (bottom left), and NEMS-GPRA 2030 Target Cost Curve No EGS Belowground Loss (bottom right)

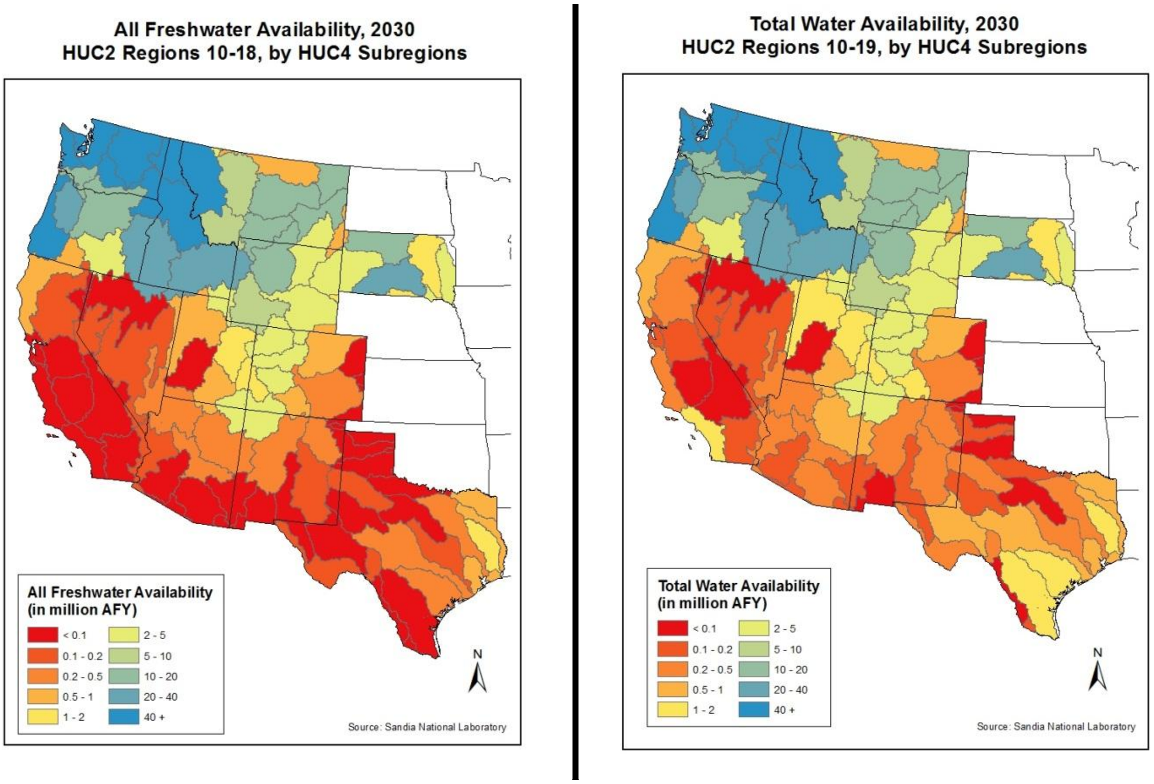

Figure 3: Water Availability Metrics Developed by Sandia National Laboratories (Source: Tidwell 2012): Freshwater Availability (left) and Total Water Availability (right)

The metrics mapped not only consider the physical availability of water, but also attempt to consider the political and economic availability of water. Figure 3 presents a summary of the estimated freshwater availability and total water availability. The freshwater availability metric includes unappropriated water, water that might be available for purchase from low-value agriculture, and renewable groundwater. The total water availability metric includes all of the freshwater sources plus estimates of brackish groundwater and municipal wastewater. These data indicate that water availability is fairly limited in many of the areas with significant near- and medium-term geothermal potential. Likely areas of conflict include most of California and Nevada. This highlights the importance of utilizing dry cooling systems when possible and minimizing freshwater consumption throughout the life cycle of geothermal power development.

CONCLUSIONS

A range of water-energy related challenges, trade-offs, and opportunities were identified relating to the development of geothermal systems. It was shown that dry cooling systems can significantly reduce water consumption for geothermal plants compared to wet or hybrid systems; however they come at a cost of an energy penalty that increases when power is the most valuable in the summer. Flash plants typically use condensate to run wet cooling systems, however this comes at a cost of reduced reservoir sustainability. Supplemental injection programs can extend the life of the reservoir but consume large quantities of water relative to other electric generation technologies. The large resource base for enhanced geothermal systems (EGS) represents a major opportunity for the geothermal industry; however, depending upon geology, these systems can be quite "thirsty" and require large quantities of make-up water due to below ground reservoir losses. Identifying potential sources of compatible degraded or low quality water for use for make-up injection for EGS and flash systems represents an important opportunity to reduce the impacts of geothermal development on fresh water resources. The importance of identifying alternative water sources for geothermal systems is heightened by the fact that a large fraction of the geothermal resource is located in areas already experiencing water stress.

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