Federal Policy Documentation and Geothermal Water Consumption: Policy Gaps and Needs

J.N. Schroeder,¹ C.B. Harto, and C.E. Clark

Argonne National Laboratory

955 L'Enfant Plaza SW, Suite 6000, Washington, DC USA 20024

ABSTRACT

With U.S. geothermal power production expected to more than triple by 2040, and the majority of this growth expected to occur in arid and water-constrained areas, it is imperative that decision-makers understand the potential long-term limitations to and tradeoffs of geothermal development due to water availability. To this end, water consumption data, including documentation triggered by the National Environmental Policy Act (NEPA) of 1969, production and injection data, and water permit data, were collected from state and federal environmental policy sources in an effort to determine water consumption across the lifecycle of geothermal power plants. Values extracted from these sources were analyzed to estimate water usage during well drilling; to identify sourcing of water for well drilling, well stimulation, and plant operations; and to estimate operational water usage at the plant level. Nevada data were also compared on a facility-by-facility basis with other publicly available water consumption data, to create a complete picture of water usage and consumption at these facilities. This analysis represents a unique method of capturing project-level water data for geothermal projects;

¹ Corresponding author at: Argonne National Laboratory, 955 L'Enfant Plaza SW, Suite 6000, Washington, DC USA 20024, Tel: 202-488-2420, E-mail address: jschroeder@anl.gov

however, a lack of statutory and legal requirements for such data and data quality result in significant data gaps, which are also explored.

Keywords: geothermal, water, policy, life cycle assessment, water consumption, NEPA

1. Introduction

In the U.S., geothermal energy is increasingly recognized for its potential to reduce carbon emissions and dependence on foreign oil (Clark et al. 2011). To this end, geothermal power production is expected to more than triple by 2040 (EIA 2013). Energy and environmental analyses are important to understanding opportunities and potential barriers to developing the geothermal energy sector. This paper focuses on water-related aspects and impacts of geothermal energy development because water is a key conveyer of heat within a geothermal system and geothermal energy production utilizes water throughout its lifecycle. Regarding water, this work assesses water consumption, which is defined as “water that is withdrawn from a resource such as a river, lake, or non-geothermal aquifer that is not returned to that resource” (Clark et al. 2013). This work focuses on publicly available water data in the form of production and injection data, permit data, and data obtained from NEPA documentation.

Geothermal energy production encompasses a variety of technologies. In this report we refer to two geothermal power-generating technologies: hydrothermal binary and hydrothermal flash. In binary-cycle plants, the geothermal fluid (a heated, subsurface fluid distinct from groundwater, also known as geofluid) is pumped from a well and flows through a heat exchanger to warm a secondary fluid, which is often referred to as the “working fluid.” The working fluid has a lower boiling point than the geofluid. In flash-cycle plants, the geofluid is rapidly vaporized or “flashed,” either as it ascends from the well or at the plant, where the geofluid flows into a tank held at a much lower pressure. The vapor drives a turbine, which then drives a

generator (Clark et al. 2011). Water is consumed at these facilities during the lifecycle in a variety of ways. Water is used during well drilling, during the construction of the facility, and during the operations phase. During operation, facilities can be cooled with water (wet cooling), with air (dry cooling), or with a combination of both (hybrid cooling). Additionally, another kind of geothermal technology referenced in this paper is an enhanced geothermal system (EGS). EGS relies on engineering (or creating/modifying) a reservoir where heat exists but water availability or permeability may be low (Clark et al. 2013). During a process known as stimulation, water is injected underground at high pressure to create a flow network and reservoir. This process is similar, though distinct, from the hydrofracking process used in the oil and gas industry, as stimulation does not aim to create new fractures, but rather slightly widen existing fracture networks.

Geothermal resources are most prevalent in the arid western United States. This geographic area is already severely water constrained, and further demand for water resources by geothermal development is something that should be carefully analyzed.

At the same time, there is a dearth of information available in the public domain on geothermal water usage. For example, water consumption information is not a reporting requirement of the Energy Information Administration (EIA) Annual Electric Generator Survey for facilities that generate less than 100 MW. And because geothermal power plant units, which are generally individually quite small in terms of capacity (certainly much less than 100MW in the United States) and are typically managed and permitted independently, rather than as a whole plant, these facilities frequently fall below the threshold for reporting water information. State policies and laws also fail to capture relevant geothermal water use information. For example, production and injection reports, required of geothermal wells on a monthly basis, are self-

reported and occasionally erroneous. Also, water permits, required in many western states, may fail to capture all the information necessary to gain a complete picture of what total water consumption at a geothermal facility actually entails. Finally, the United States Geological Survey (USGS), which is normally responsible for reporting this kind of information, has not reported on water usage or consumption since 1995.

The current analysis was conducted as part of an ongoing series of reports sponsored by the U.S. Department of Energy (DOE) Geothermal Technologies Office (GTO). The reports evaluate a range of water-related issues surrounding geothermal power production (Clark et al. 2011, 2012, 2013; Schroeder et al. 2014a).

The data presented here build upon previous work to rectify data limitations and improve lifecycle freshwater consumption estimates, particularly in areas such as well drilling and water sourcing. Another goal of this research is to work toward identifying gaps in applicable policies and laws that, if addressed in the future, would yield better data concerning water consumption and would deepen understanding of the regional water stress that geothermal areas in the western United States may face in the coming decades. In previous analysis by Argonne, areas of significant water stress were also identified as geothermal-rich resource areas, thus making this analysis important and applicable (Clark et al. 2013).

With the aforementioned data needs in mind, a comprehensive review of relevant environmental documentation and regulations was conducted to obtain information about water usage related to geothermal projects. An analysis of relevant laws and policies was conducted as a means of identifying gaps where more information could yield better, and more informed, decision making around geothermal energy development. Reports generated by the National Environmental Policy Act of 1969 (NEPA) were used to obtain estimates of water sourcing for

drilling, stimulation, and operational water usage. These reports were also used to obtain information and estimates about water consumption for geothermal well drilling activities and plant-level estimates of operational water usage. This review was intended to capture information that a literature search might miss, as well as to complement such a process. In addition, information was pulled from production and injection reports and the water permit database for the state of Nevada. Nevada is the second-largest state in terms of number of geothermal projects and also posts much of its water permit and production information online. When these data were combined, a more robust estimate of geothermal water consumption was generated.

2. Materials and Methods

2.1 Federal and State Geothermal Regulatory Analysis

When the sources of water for different geothermal energy stages were analyzed, significant variability was observed at the state and federal levels regarding what constitutes a geothermal resource and the extent that it is different from a water resource (e.g., groundwater). 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 the law was intended to clarify and simplify the leasing process, it left unresolved whether or not geothermal resources were included in reservations of mineral rights or whether they constituted water resources (Schroeder et al. 2014a). This uncertainty filtered down to the state level, where these resources are defined in many different ways. As part of this work, the background and context of geothermal definitions at the state and federal level were analyzed to present an understanding of the regulatory complexity of this field and of how these definitions influence the availability of water consumption information.

2.2. National Environmental Policy Act

NEPA is a federal law that requires completion of an environmental assessment (EA) and/or environmental impact statement (EIS) for any major action by a federal agency that may affect the environment. Because many geothermal projects in the western United States occur on lands owned by the federal government, which are then subsequently leased for development, the NEPA process is triggered and considerable documentation is created. This documentation represents a unique opportunity to obtain otherwise unpublished information. For the current research, water use estimates and sourcing information for well drilling and stimulation, as well as operational water usage, were targeted.

The NEPA documentation review process began with the systematic researching of geothermal projects through the U.S. Department of the Interior (DOI) Bureau of Land Management (BLM) on a state-by-state basis. Starting with Nevada, NEPA documents posted on BLM field office websites were searched for relevancy and availability. Documents from older projects and/or those that had not yet been made available online yet were requested from the appropriate field office, as needed. A thorough search of BLM documents was supplemented by contacting the DOE Office of NEPA Compliance, which also produced documentation for the cases in which a geothermal project had received DOE funds, but was not on federal land.

The NEPA search and review process was conducted for all states with active geothermal areas. Altogether, 34 NEPA documents representing 38 separate geothermal projects were obtained. Many projects that were initially identified ended up occurring on private land, which meant that the NEPA process was not triggered; thus, no documentation was produced. In addition, research found that many projects were old enough such that the NEPA documents that

were available contained very little information about water usage. It was not standard practice to include such information in the 1970s, 1980s, and even parts of the 1990s.

After the NEPA data were collected, they were used to analyze water consumption information for geothermal well drilling, as well as water sourcing information for well drilling, stimulation, and operational water usage. Note that water consumption, in the context of this paper, is defined as freshwater consumption from all sources.

In addition, it is important to note that documentation collected during the NEPA process is largely prospective; that is, because the analysis is conducted before the actual construction of the facility, numerous assumptions (e.g., configuration, levels of production, and cooling technologies) are made. Thus, it is recognized that there may be changes to these approaches later on in the development process. Obtaining operational water consumption directly from operating geothermal power plants is preferred; unfortunately, for analysts wanting to evaluate water use, these data are not publicly reported for most geothermal power plants in the United States. While water consumption data are indeed asked of plants that generate 100 MW or greater on the EIA 860 datasheet, they are not required from smaller facilities. Furthermore, geothermal power plants are not sufficiently large in terms of capacity that they would appear in the EIA 860 sheet. Although some geothermal fields, such as The Geysers, collectively generate more than 725 MW, they comprise many individual generators that do not meet this threshold.

2.3. Production and Injection Reports

To complement analysis conducted previously by Argonne National Laboratory (Argonne) for geothermal facilities in California (Clark et al. 2011), production and injection data for Nevada geothermal plants were obtained from the Nevada Division of Minerals (<http://www.nbmng.unr.edu/lists/Production/index.html>) for 19 facilities across the state:

Beowawe, Blue Mountain Faulkner, Brady Hot Springs, Desert Peak 1, Desert Peak 2, Dixie Valley, Empire San Emidio, Richard Burdette (Galena 1), Galena 2, Galena 3, Moana, Salt Wells, Soda Lake, Steamboat 1/1A, Steamboat II, Steamboat III, Steamboat Hills, Stillwater, and Wabuska.

These data were self-reported by the facility's operator on a monthly basis for each production and injection well utilized by a plant. The report specifies, at a minimum, the gallons of geothermal fluid produced or injected for each well, as well as the temperature of that fluid. By using these data, it was possible to perform a mass balance conversion and derive the pounds of water produced or injected each month. By comparing production and injection data within the same month, makeup and/or loss rates were estimated for each facility. Further calculations included annual loss and/or makeup in gallons per year and average annual loss and/or makeup per megawatt-hour equivalent.

While this was done for all facilities listed, the production/injection datasets were not all useful for several reasons. The most prevalent explanation was that production/injection data were either inadequately reported or the facility was too recently constructed. In these cases, because of a lack of data, a robust trend was unavailable. Thus, only datasets with a minimum of three continuous full years of production/injection data were chosen for further analysis (i.e., Blue Mountain, Moana, San Emidio, and Salt Wells were excluded). In addition, data from the multiple facilities in the Steamboat Complex (Steamboat 1/1A, II, III, Steamboat Hills, Richard Burdette, Galena 2, and Galena 3) were combined into one facility because some of the plants share injection wells. This yielded a total of 12 facilities analyzed.

2.4. Water Permit Data

An extensive review of all applicable water permits issued by the State of Nevada for geothermal facilities was conducted through the Nevada Division of Water Resources Permit Search web portal (<http://water.nv.gov/data/permit/index.cfm>). A database was constructed that linked permits with their geothermal facility. This was done in an attempt to compare permitted water usage with makeup and loss rates from the self-reported datasets mentioned previously. Two types of permits are issued for geothermal power plants in Nevada for geofluid extraction and freshwater consumption. Permits for the extraction of geofluid typically also specify permissible fluid losses (i.e., fluid not reinjected). Note also that the permit data indicate only how much water a geothermal power plant is allowed to use. The data do not indicate how much a plant is actually using and therefore should be viewed as a maximum value for that specific plant.

3. Results

3.1 Regulatory Analysis

The BLM Programmatic Environmental Impact Statement (PEIS) for the federal geothermal leasing program states that, “The geothermal lease is for the heat in the federal mineral estate. Unless specifically owned in fee, the fluid part of the resource falls under state water laws” (Callison 2010; DOI 2008). This definition can then be compared to the federal (and generally understood) 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). Thus, geothermal permitting is a complicated process that changes depending on the state in which development is located and whether it is located on public or private land (Schroeder et al. 2014a). This distinction is especially problematic because, while the federal government may manage the heat resource, state governments generally manage the use and/or consumption of water resources. Geothermal energy is a comingled resource (the heat is combined with the water), so if regulatory and governance mechanisms are not in sync, so that, for example, the federal government defines and manages the resource differently than the state, it can potentially cause confusion.

As a result, the definition of what constitutes a geothermal resource has been left to the states to remedy, which they have done in different ways. The wide array of definitions around geothermal waters and how they are managed has led to a complex situation of inconsistent tracking of these waters across states (Schroeder et al. 2014a). Table 1 outlines the difference in geothermal definitions for states with active geothermal development as identified by GEA (2014). For example, in Nevada, the state’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 the word “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 (Schroeder et al. 2014a, b).

Conversely, in Utah, geothermal fluids are treated 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 for 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; Schroeder et al. 2014b).

Finally, 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; Schroeder et al. 2014a). In reality, the act bifurcates the resource into high- and low-temperature categories (with 212°F being the dividing line), 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 affect the groundwater for prior water rights (Stoel Rives LLP, 2009; Schroeder et al., 2014a).

3.2. Well Drilling Water Use Estimates

With this understanding of the complicated regulatory and policy landscape within which geothermal energy operates, we can examine how water consumption information was ultimately obtained. All available NEPA documentation was reviewed to identify water volume estimates for geothermal well drilling. In all, NEPA documents representing 21 separate geothermal facilities contained some estimation of this kind of data. These documents were further separated based on geothermal well type—specifically, observation, exploration, or production/injection wells. An observation well is drilled to provide physical and chemical data on groundwater and geology in an area. An exploration well is later drilled to conclusively determine the presence or absence of a geothermal resource. Production and injection wells are the final wells drilled and are part of the production of geothermal energy. Once the well types were separated, the data were analyzed to determine the cubic meters (m^3) consumed per 1,000 meters (m) drilled.

Several assumptions were made to aid the analysis. First, three facilities gave a daily water usage estimate but failed to give an estimate for the length of the drilling period, which made it impossible to estimate total water volume. Therefore, it was assumed these data points would be inaccurate and so they were excluded from consideration. Second, if a range for final well depth was given, both endpoints of this range were used, as it was assumed this would provide a more robust comparison. Third, if a range for water volume was given, the median value of this range was used. Finally, for sizing exploration wells, if no drilling diameter was provided and it was not otherwise specified, it was assumed that the well was a conventional, full-sized exploration well and not a slim well. See Clark et al. (2013) for further details and discussion. The analysis indicated that, for the facilities evaluated, estimates for water use averaged $1,700 \text{ m}^3$ per 1,000 m drilled for observation wells, $1,900 \text{ m}^3$ per 1,000 m drilled for

exploration wells, and 2,300 m³ per 1,000 m drilled for production/injection wells. The estimations for specific projects are provided in Tables 2 - 4.

3.3. Source Water for Drilling, Stimulation, and Operation Activities

NEPA documents were also used to determine the source of water for well drilling, stimulation, and power plant operations. For this analysis, *groundwater* is defined as water derived from aquifers and other sources belowground. Groundwater is different and hydrologically distinct from *geofluid*, because geofluid is not of sufficient quality to be potable because of its high salinity and concentration of total dissolved solids (TDS). For example, Clark et al. (2011) reported that 80% of TDS samples in the Argonne Geothermal Geochemical Database (AGGD) had a value of less than 5,000 mg/L and that the majority of TDS measurements fell between 500 and 5,000 mg/L, though some reservoirs have TDS values outside this range (Scheiber et al. 2012; RMT, Inc. 2010). In addition, geofluid is generally much warmer than typical groundwater sources. Typical groundwater temperatures in the United States range from between 7°C and 27°C depending on location (Wellowner.org 2014), while the generally accepted industry definition of a binary resource, a type of geothermal production configuration that typically requires a lower temperature threshold for feasibility, does not begin until 100°C. Finally, groundwater and geofluid sources are often accessed differently via the permitting process at the state level. *Surface water* is defined in this paper as water that is available aboveground in a stream, lake, or river and that can be obtained without drilling a well. *Condensate* is defined in this paper as water that is obtained from condensing the steam that exits the flash vessel. *Stormwater* is defined in this paper as atmospheric water that falls to the earth as precipitation and is then collected on the earth's surface. Finally, *treated wastewater* is defined in

this paper as municipal sewage/effluent that is treated at a publicly owned treatment works before being discharged.

The results of this analysis found that for drilling, approximately 83%—or 20 of the 24 geothermal sites analyzed that included a drilling component—used groundwater as their primary source of drilling water. For the remaining sites, there were two instances (about 8%) of surface water as a source, one instance (about 4%) of geofluid, and one (about 4%) instance of condensate from an existing power plant as a source for drilling water. This same site also used both geofluid and condensate for drilling water.

For stimulation of enhanced geothermal system (EGS) wells, there was more variation in the number of sources used for this activity as compared to drilling. Of the seven sites that provided source water information in their documentation, there were three instances in which groundwater was used as a source of stimulation water, or approximately 43% of the time. For the remaining sites, there was one instance (equating to about 14%) involving each of the following uses: surface water, treated wastewater, condensate, and stormwater. For this analysis, there were seven data points for five sites; this occurred because some projects use multiple sources of water for stimulation.

Finally, for operational water usage, 11 of the 15 sites that provided data in this area used groundwater, representing almost half of the total (approximately 46%). Surface water was used in six instances (25%), condensate was used in four instances (17%), and treated geofluid was used in three instances (13%). There were 24 data points for 15 sites because, as mentioned previously, multiple water sources were used simultaneously at several sites.

3.4. Operational Water Usage

Table 5 provides geofluid production and injection estimates for 12 geothermal facilities in Nevada. In addition, in past years Argonne had conducted a lifecycle analysis on one facility in California, Casa Diablo, which was included here as well for continuity (Clark et al. 2011). Plant configuration, cooling system type, capacity, production and injection amounts, and water permit information were all analyzed. In all cases, the reported flows were less than the permitted flows, which indicates a level of consistency between the two datasets. In most cases, the losses reported were significantly lower than those permitted by the state. Note there may be an incentive to under-report production and injection numbers so as to comply with state permits, which may explain why the losses were almost always significantly lower than the permitted amount.

The geofluid production and injection data presented in Table 5 are unlikely to be useful for quantifying water consumption for air-cooled, hybrid-cooled, or wet-cooled binary systems (because the closed-loop nature of the binary system would require outside water sources for cooling); however they may be useful for estimating geofluid losses from wet-cooled flash systems. Unlike the other system designs, wet-cooled flash systems typically exhibit large and relatively consistent differences between production and injection over time, which should be easier to resolve despite the small errors in the underlying data. The error in the underlying data was estimated to be on the order of 2–3% of production flow based upon the difference observed between production and injection flows for air-cooled systems at Casa Diablo, Steamboat, and Stillwater, which would be expected to operate with equal flow rates. The differences between production and injection for the wet-cooled flash systems in Table 5 (Beowawe, Desert Peak 1, Dixie Valley, and Salton Sea) range from 17% to 25%, which translates to 6 to 10 m³/MWh.

These values should still represent a reasonable approximation of the geofluid loss for these systems because they lie significantly outside the range of estimated error in the data.

Aboveground operational water consumption estimates obtained from NEPA documentation are presented in Table 6. Consumption of operational water from wet-cooled flash plants ranged from approximately 3 to 14 m³/MWh. Operational water consumption from wet-cooled binary plants was slightly higher, ranging from approximately 6 to 17 m³/MWh. Given the small number of data points available, this difference is hard to resolve. However, there are two plausible factors that could lead to lower water consumption at flash plants relative to binary plants: (1) flash plants typically operate with higher temperature geofluid, which makes them more thermodynamically efficient; and (2) the low data point for flash systems was based upon supplemental water injection for reservoir augmentation, which may not account for 100% replacement of lost geofluid. The practice of injecting makeup 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. Thus, when supplemental injection is not practiced, consumption levels of non-geofluid operational water are minimal and similar to those of dry-cooled systems. In contrast, binary plants are almost always operated as closed-loop systems, in which all the produced geofluid is directly reinjected; thus, binary plants require an external source of water for cooling if a wet- or hybrid-cooling system is used.

Hybrid cooling systems combine air and wet cooling, although they typically rely on air, reserving supplemental wet cooling for warm weather. This supplemental cooling can increase the power output in the summer when power prices are highest, but it requires significantly less water than a completely wet-cooled system. In the analysis, water consumption for hybrid cooling systems ranged from about 1 m³/MWh to nearly 7 m³/MWh. In general, these systems

are expected to display a high variance in water consumption because the nature of their operation allows for a wide range of water consumption, driven by the operational decision of how often to operate the wet portion of the cooling system.

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 approximately $0.004 \text{ m}^3/\text{MWh}$ to just over $0.1 \text{ m}^3/\text{MWh}$.

Although the presented data represent the best collection of operational water consumption from geothermal power plants that currently exist, some important caveats should be made. First, the production and injection data reported to the states are imprecise and only useful for roughly approximating geofluid losses from wet-cooled flash systems. Second, the data from state water permits indicate how much water a geothermal power plant is allowed to use, but they do not indicate how much a plant is actually using and therefore should be viewed as a maximum value for that specific plant. In addition, as stated previously, much of the NEPA documentation is prospective, because the NEPA process is conducted before the facility is constructed and requires numerous assumptions to be made during the analysis. In some cases, this may be how the facility is developed; however, in other instances, there could be changes to these approaches as the facility is constructed and operated.

The values presented in this section should be considered rough order-of-magnitude approximations of what the operational water consumption from different types of geothermal systems is likely to be, rather than precise estimates for any given power plant or system type. Table 7 summarizes the three types of data sources analyzed in this section, identifies how each

dataset can contribute to improved understanding of water consumption for geothermal power production, and summarizes the limitations and challenges associated with utilizing each type of source.

3.5. Results Summary

The results show that although some data on water consumption for various stages of the geothermal lifecycle are available in the public domain, they are limited. In addition, much of the data is challenging to use or flawed in some way (e.g., prospective data from NEPA documents, permitted versus actual water use from water permits, and errors in production and injection data). Thus, the data should be utilized with care and complete understanding of the limitations of each data point. The next two sections address these data limitations in more detail and suggest some potential solutions.

4. Discussion of Data Gaps in U.S. Geothermal Energy Production

During the analysis, it became evident that creating a comprehensive picture of water use in U.S. geothermal energy production was inhibited by a complex regulatory and reporting landscape. The challenge of navigating this bureaucracy can lead to gaps in knowledge and, consequently, data, particularly surrounding water consumption. The following discussion identifies the gaps and challenges to be addressed by the policy community and proposes solutions to address them.

4.1. What Is a Geothermal Resource?

When the sources of water for different geothermal energy stages were being analyzed, significant variability was observed at the state and federal levels regarding what constitutes a geothermal resource and the extent that it is different from a water resource (e.g., groundwater). These inconsistencies within states are magnified when attempting to compare geothermal plants

between states. This is significant because the differences in definitions at the state level have led to multiple regulatory agencies having management authority for geothermal resources within the states. This means geothermal data, particularly geothermal water consumption data, are not necessarily concentrated within one department or agency, making these data especially hard to obtain. Given the broad differences among states, consistency in how geothermal waters are managed is likely to be an unattainable goal (Schroeder et al. 2014a).

4.2. Errors with Production and Injection Reporting

Another murky avenue of water consumption information exists in production and injection reports, which we attempted to review for this paper. However, recent discussions with state officials and industry representatives have also called into question the precision and value of the production and injection data for determining freshwater consumption from geothermal power plants (Clark et al. 2013). Often these data are reported based upon a single monthly point measurement of flow rates and temperatures rather than monthly averages, which can introduce monthly variability into the data.

There is also the potential for error when converting from mass flows to volumetric flows. For example, because TDS are not reported, they had to be estimated and were assumed to be constant (between production and injection) when the required density corrections were performed. While this is generally not an issue for binary systems, for flash systems it is likely that the TDS concentration is higher in the injectate as water has been lost due to flashing. The density will therefore be higher than would be calculated using this method, and conversion from volumetric to mass flow rates would show a slightly greater mass loss in the flash system than what is actually occurring.

Furthermore, failure and calibration issues with flowmeters have been suspected as a common issue with the reported production and injection data. In this analysis, an effort was made to exclude any data points that appeared to be anomalies from the averages, but some measurement error likely still remains within the datasets. For example, two air-cooled binary power plants within the dataset show a difference of approximately 2% between the production and injection volumes calculated by this method, despite the fact that these systems operate in a closed-loop manner in which no loss of geofluid is expected. However, this should give a reasonable approximation of the level of error expected in the use of these data.

Finding technological solutions to make production and injection data more precise would help resolve some of the aforementioned issues. These solutions might include more frequent sampling, rather than the one-off monthly approach currently utilized. Also, more frequent calibration of testing instruments might be beneficial. To this end, there are several guides for best practices of geothermal production measurement and flowmeter calibration in the public space that can be referenced (SPE International 2013; Richardson 2013). Finally, accounting for TDS measurements may improve accuracy when volume flows are converted to mass flows.

4.3. Complicated Permitting Structure

Finally, the complicated permitting structure for geothermal energy also represents a significant source of confusion. In Nevada, for example, while water permits are publicly available online through the web portal of the Division of Water Resource, the permits are organized not by plant but by applicant. This grouping may make sense up front; however, in the analysis presented in this paper, it was not unusual for one facility to have multiple applicants, some of which used different names for the same facility. In addition, a plant may acquire old

permits for water in the vicinity (which makes sense under the Prior Appropriation Doctrine, in which the date is important) or apply for new water permits. Geothermal companies also sometimes prospectively apply for water permits years before construction of a plant begins, often through shell companies or limited liability corporations (LLCs), whose name may have nothing to do with the facility's name. Navigating through all this information and trying to track down all permits that may apply to one site is extremely difficult. It would be much more efficient to sort permits by site or, perhaps, organize them by location through global positioning system (GPS) coordinates and maps. In this way, it would be simpler and quicker to ascertain which permits belong to which sites.

In addition to the water permit process, the general geothermal-permitting process in many states can also be extremely difficult to navigate because of multiple agency involvement. For example, in California, the Division of Oil, Gas, and Geothermal Resources collects and organizes production and injection data from geothermal facilities. However, water permitting is handled by a different agency. This is also the case in Nevada where the Nevada Division of Minerals handles well reporting, but the Nevada Division of Water Resources handles water permits and water management on site. This cross-government form of management is likely a product of the confusion over what constitutes a geothermal resource, as discussed previously. There also exists conflict over what level of government is responsible for regulation. In California, for example, if a power plant is less than 50 MW, it is regulated at the county level. However, if it is over this threshold, it is permitted at the state level by the California Energy Commission (CEC 2007). This distinction can make a significant difference in the time it takes to obtain a permit (e.g., 3 months for the former versus at least 1 year or more for the latter), which is why in California, there are so many 49-MW power plants.

Some solutions to this issue are already being implemented, most notably, the DOE Geothermal Regulatory Roadmap (GRR) initiative (<http://en.openei.org/wiki/GRR>), which is a comprehensive attempt by the Geothermal Technologies Office and the National Renewable Energy Laboratory (NREL) to work with state and federal partners to streamline the geothermal permitting process by identifying timelines and potential areas of overlap and/or concern. From the GRR website, “Geothermal industry stakeholders have identified the permitting process as one of the most significant barriers to geothermal power project development. Drilling exploration and development wells is expensive. A protracted time line has a critical impact on the development of geothermal resources, and often it’s not a single issue or bottleneck, but a combination of multiple or overlapping processes that impact a project.” Initiatives like this are critical to making geothermal energy cost competitive with other renewable energy technologies in the future.

In addition, NREL is also incorporating NEPA documentation into the DOE Open Energy Information website, OpenEI (<http://en.openei.org>). NEPA documentation, such as EAs and EISs, are inputted, tagged, and summarized with relevant information, such as geothermal area, lead agency, project phase, and managing field office, among others. This database could be a potential place to incorporate the kinds of geothermal data gaps discussed previously, such as operational water consumption, water sourcing, and permit information.

The National Geothermal Data System (NGDS) is another solution to the issues identified in this analysis. Funded by the DOE Geothermal Technologies Office, this distributed data system, accessed from a single website (www.geothermaldata.org), links geothermal data repositories across the United States and other countries. NGDS contains geothermal data and information contributed by private industries, state and federal agencies, and businesses. It

allows users to search for location-specific and other geothermal information. From the NGDS website, this resource can be used to “determine geothermal potential, guide exploration and development, make data-driven policy decisions, minimize development risks, understand how geothermal activities affect your community and the environment, and guide investments.” New data are being provided regularly. This kind of centralized, aggregating website could also host information about drilling volumes, operational water consumption, and other geothermal water information and thus provide a crucial tool.

As an example of integration with NGDS, the Arizona Natural Resources Review Council unanimously approved adoption of a plan for developing a Natural Resources Decision Support System (NRDSS) to link data, documents, and GIS layers with its nine agencies dealing with natural resources, environmental issues, and transportation and with corresponding federal agencies. The system will be built around the U.S. Geosciences Information Network (USGIN), a data integration framework that underlies NGDS. The Arizona Governor is poised to implement the system. USGIN will have three integrated components: it will contain the Arizona GIS repository and clearinghouse (AZGEO); it will be a single point of contact (SPOC) (i.e., the designated source) for information for federal agencies operating in Arizona; and it will be a system clearinghouse for discovering, accessing, and integrating documents and data that will be available via system and agency web portals through online catalogs. As is the case for NGDS, each data provider will maintain control of its own data, documents, and maps and will make them accessible through web services provided via a distributed network. The federal agencies will share their materials from a node on the system created under the auspices of the Western Regional Partnership, a consortium of 20+ federal agencies and governors of five western states. The system can be expanded to include other agencies. According to the Arizona Geological

Survey, this will be the first interoperable network of state natural resources data in the country, the first digital SPOC, and the first federal-state system that meets the requirements of the White House Open Data Access initiative.

Voluntary and mandatory reporting of hydraulic fracturing fluids used in oil and gas development are managed through FracFocus 2.0 (<http://fracfocus.org>) and may serve as an example of the type of fluid data that could be reported to the NGDS system. Some state agencies that have required reporting to FracFocus include the North Dakota Department of Mineral Resources, the Colorado Oil and Gas Conservation Commission, and the Texas Railroad Commission, among others. Such mandatory reporting for geothermal water consumption could be modeled on these provisions.

5. Conclusions and Policy Implications

By analyzing and combining information from federal environmental documentation datasets, figures concerning water usage were estimated for geothermal well drilling; water sourcing data for well drilling, well stimulation, and plant operation; and operational water usage at the facility level. Estimates of drilling water usage were found to average between 1,700 and 2,300 m³ per 1,000 feet drilled, depending on well type. In addition, groundwater was found to be the preferred source of water, if available, for all activities analyzed. This finding may be due to the fact that, in the West, groundwater sources do not generally require a water right and so are potentially more accessible than surface water sources. Finally, rough ranges of operational water consumption for different types of geothermal power plants were identified. The approach utilized in this analysis identified information not otherwise readily available in the literature and helped improve and inform analysis of geothermal energy water consumption, while taking into account and analyzing the inherent limitations of the available datasets.

On the policy side, several gaps that were identified can be addressed to streamline geothermal water consumption reporting; these are summarized in Table 8. Most significantly, attempts should be made to address the confusion over what constitutes a geothermal resource, both at the state and federal levels. While this is likely the hardest issue to tackle, it would have the biggest payout. Streamlining geothermal definitions would also allow for easier and more robust comparison across states. In addition, at the federal level, requiring water consumption reporting for all facilities listed on the EIA 860 data sheet would go a long way toward understanding geothermal water consumption at the plant level. Modifying the water consumption data request to include smaller facilities is not a simple task. In order for the EIA to modify the sheet to include facilities smaller than 100 MW (the vast majority of geothermal facilities), approval of the Office of Management and Budget must first be obtained, due to the Paperwork Reduction Act of 1995 (USC 2014). While inquiries to this effect have been made to EIA in the past, we were told that there was a forthcoming update to the questionnaires and that we should wait until this time to pursue the matter further. This may be among the easiest “fixes” with the most immediate payback. Solutions to other gaps, such as requiring more frequent production and injection reporting or requiring TDS information with such reports, needs to occur at the state level and as such may take longer to remedy.

Another gap does not fit as easily into the categories above but is just as important. This gap is the lack of publicly available information on the volumes of water necessary for EGS stimulation. While the sourcing of stimulation water is covered in this analysis, actual volumes of water, as well as additives, are covered in Clark et al. (2013). These figures were arrived at by a comprehensive literature review, and with the exception of one site (the Altarock/Newberry Volcano site in Oregon), none of the data were available in the public domain. This lack of

publicly available data represents a significant gap in understanding the water resource impacts of this water-intensive technology. As the geothermal industry progresses, more low-temperature resources will be targeted, making this gap particularly problematic. Reporting of drilling and stimulation fluid volumes to a centralized data repository, such as the NGDS, could address this gap.

The need for better data is a concern not only for geothermal but also for many industries. Highlighting this need and identifying both the technical and policy-related issues that lead to this lack of data are critical first steps in addressing the problem.

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Table 1 State-level geothermal water management definitions, laws, and principles.

State	Geothermal Resource 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	<i>Arizona Revised Statutes (ARS)</i> 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 (e.g., The Geysers sits at ~2,400 ft, where water has a boiling point of 97.6°C, or 207.7°F)	<i>California Public Resources Code</i> , Division 3, Chapter 4, Sections 3701 and 3703.1	Correlative Rights
Idaho	Neither a mineral nor water (<i>sui generis</i>), though managed under the Department of Water	Resource temperature of 212°F (or 100°C)	Idaho Geothermal Resources Act in <i>Idaho Statutes</i> 42-4002(c)	Prior Appropriation
Nevada	Defined as a mineral but managed as a water resource by the Department of Minerals	NA	<i>Nevada Revised Statutes (NRS)</i> 534A.010	Prior Appropriation
New Mexico	Mineral and water	Above 250° F, the resource is classified as a mineral; at or below 250° F, it is classified as water.	<i>New Mexico Administrative Code (NMAC)</i> , 19.14.1.7(o) and 19.14.1.7(r)	Prior Appropriation
Oregon	Mineral and water	Above 250° F, the resource is classified as a mineral; at or below 250° F, it is classified as water.	<i>Oregon Revised Statutes (ORS)</i> , 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 <i>Utah Code</i> , Title 73, Chapter 22, Sections 3 and 4	Prior Appropriation

^a NA = not applicable.

Source: Schroeder et al. (2014)

Table 2

Water use estimates for observation wells.

Project	Observation Well (m³)	Depth (m)	Consumption (m³/1,000 m)
Dixie Meadows ^a	1,700	900	1,900
Drum Mountains ^b	1,600	900	1,700
Leach Hot Springs ^c	1,700	900	1,900
New York Canyon ^d	4,200	3,000	1,400
Average estimated consumption			1,700

Sources: ^a BLM 2011a; ^b BLM 2011e; ^c BLM 2011c; ^d BLM 2010a**Table 3**

Water use estimates for exploration wells.

Project	Exploration Well (m³)	Depth (m)	Consumption (m³/1,000 m)
Buffalo Valley ^a	3,400	2,100	1,600
Carson Lake ^b	3,400	2,400	1,400
Carson Lake ^b	3,400	3,000	1,100
Clayton Valley ^c	9,500	3,000	3,100
Glass Mountain ^d	1,400	2,700	520
Naknek ^e	9,500	3,700	2,600
San Emidio ^f	2,300	1,100	2,100
Tungsten Mountain ^g	5,300	2,100	2,500
Average estimated consumption			1,900

Sources: ^a BLM 2006; ^b BLM 2008; ^c BLM 2011b; ^d MHA 2002; ^e DOE 2010; ^f BLM 2010c; ^g BLM 2012

Table 4

Water use estimates for production/injection wells.

Project	Production/Injection Well (m³)	Depth (m)	Consumption (m³/1,000 m)
Desert Peak ^a	7,600	1,700	4,500
Desert Peak ^a	7,600	2,000	3,800
Dixie Meadows ^b	5,300	3,000	1,700
Drum Mountains ^c	5,700	3,000	1,900
Fourmile Hill ^d	3,000	2,600	1,200
Leach Hot Springs ^e	5,300	1,800	2,900
McGinness Hills ^f	720	2,100	340
Neal Hot Springs ^g	2,300	610	3,700
Neal Hot Springs ^g	2,300	1,500	1,500
Patua ^h	4,900	2,100	2,300
Patua ^h	4,900	3,000	1,600
Average estimated consumption			2,300

Table 5Geothermal power plant geofluid production and injection and state permit data.^a

Plant/Field Name	Plant Type	Cooling System Type	Rated Capacity ^b (MW)	Reported Production vs. Injection (m ³ /day)			NV Permit Data (m ³ /day)	
				Production	Injection	Difference	Permitted Production	Permitted Loss
Beowawe	Flash	Water	16.6	23,000	19,000	(4,000)	28,000	4,000
Desert Peak 1	Flash	Water	12.5	10,000	8,000	(2,000)	20,000	4,000
Dixie Valley	Flash	Water	62	53,000	40,000	(13,000)	76,000	20,000
Salton Sea	Flash	Water	336	273,000	223,000	(50,000)		
Brady Hot Springs	Binary and flash	Air and water	21.1	43,000	32,000	(11,000)	66,000	14,000
East Mesa	Binary and flash	Air and water	79	191,000	183,000	(8,000)		
Heber	Binary and flash	Air and water	85	134,000	125,000	(9,000)		
Desert Peak 2	Binary	Hybrid	11	900	600	(300)		
Soda Lake	Binary	Hybrid	26.1	23,000	23,000	0	24,000	1,000
Casa Diablo	Binary	Air	40	66,000	64,000	(2,000)		
Steamboat Complex	1 Flash, 6 binary	Air	89	209,000	213,000	5,000		
Stillwater	Binary	Air	21	28,000	27,000	(1,000)	53,000	5,000
Wabuska	Binary	Cooling ponds, not reinjected	2.2	14,000	0	(14,000)	29,000	29,000

^a All fluid volumes in this table are geofluid volumes.^b As mentioned previously, many of these plants include multiple operating units. The capacity listed is the total capacity of the field and so may represent the sum of several units.

Source: Clark et al. (2013)

Sources: ^a BLM 2003; ^b BLM 2011b; ^c BLM 2011e; ^d BLM 1998; ^e BLM 2011c; ^f BLM 2011d; ^g DOE 2009;^h BLM 2010b

Table 6

Aboveground operational water consumption estimates from NEPA documents.

Plant Name	Plant Type	Cooling System Type	Location	Water Consumption (m³/MWh)
<i>Water for Cooling</i>				
Coso Hay Ranch/China Lake	Flash	Wet	CA	2.8 ^a
Salt Wells – Vulcan	Flash	Wet	NV	14.3
East Mesa	4 Binary + 2 Flash	Wet	CA	18.4
Blue Mountain	Binary	Wet	NV	9.2
Tuscorora	Binary	Wet	NV	14.3
Patua	Binary	Wet	NV	17
Salt Wells – Vulcan	Binary	Wet	NV	17.2
Oregon Institute of Technology	Binary	Wet	OR	5.7
Coyote Canyon	Flash	Hybrid	NV	1.2
Salt Wells – Ormat	Binary	Hybrid	NV	4.2
McGinnis	Binary	Hybrid	NV	6.5
<i>Water for Other Uses</i>				
Jersey Valley	Binary	Air	NV	0.0038 ^b
Coyote Canyon	Flash or Binary	Air	NV	0.1136 ^b

^a Data includes only water used for supplementary injection to increase reservoir pressure and may not account for all geofluid consumed during cooling.

^b Water consumption includes domestic use, maintenance, and dust suppression.

Table 7

Comparison of geothermal water consumption data sources.

Data Type	What Is It Useful For?	Challenges
Production and Injection Reports	<p>Can be used to estimate the geofluid consumption from wet-cooled flash power plants.</p> <p>Values ranged from 6 to 10 m³/MWh for four power plants in Table 5.</p>	Measurement and reporting error was estimated to be on the order of 2–3% of production flow. Data are not useful for estimating freshwater consumption. Injection of additional surface water, if it occurs, distorts calculations of geofluid consumption.
State Water Permits	Can provide an estimate of the maximum geofluid or freshwater consumption from a specific plant; can also be used to provide a check on production and injection reports.	Data indicate only how much water a power plant is permitted to consume, not how much it actually is consuming. Power plants often have multiple permits, so care must be taken to ensure that all applicable permits are included in the analysis.
NEPA Documents	<p>Often provide estimates of water consumption for power plants of a specific type.</p> <p>Values from Table 6: wet-cooled flash, 3–14 m³/MWh; wet-cooled binary, 6–17 m³/MWh; all hybrid-cooled, 1–7 m³/MWh; all air-cooled, 0.004–0.1 m³/MWh</p>	Values presented in NEPA documents are often estimates made before a power plant is constructed and thus may vary from actual water consumption during operations. Care must be taken to understand the assumptions being made in generating these estimates.

Table 8

Information gaps and policy solutions summary.

Technical and Policy Gaps	Causes	Possible Solutions
Errors in production and injection reporting leading to a lack of operational geofluid consumption data	<ul style="list-style-type: none"> • Infrequent sampling of produced geofluid • Faulty and incorrectly calibrated flowmeters • No requirements for reporting chemical composition and/or density measurements during sampling 	<ul style="list-style-type: none"> • More precise flowmeters • More frequent sampling • More frequent and precise calibration of equipment • Requirements for reporting of chemical composition and density measurements to obtain accurate volume/mass conversions
Circuitous and confusing geothermal permitting process	<ul style="list-style-type: none"> • Geothermal permitting spread across different departments and agencies • Lack of project information for geothermal permits at the state level 	<ul style="list-style-type: none"> • Requirements for water permits to be sorted by project to streamline searching • Streamline permitting process at the state level by consolidating responsibility and reporting to one main agency, regardless of plant capacity
General lack of geothermal water data	<ul style="list-style-type: none"> • Water consumption information not required by EIA for facilities less than 100 MW • Consumption information is closely guarded by industry 	<ul style="list-style-type: none"> • Require all operators to list water sourcing and consumption data on the EIA 860 form • Encourage submittal of geothermal water information to NGDS or similar centralized repository
Inconsistent water/groundwater/geothermal definitions at the state and federal level	<ul style="list-style-type: none"> • Historical confusion over nature of geothermal resource and whether it is a water or mineral resource 	<ul style="list-style-type: none"> • Identify inconsistencies across state, as a starting point • Establish clear and concise federal guidance