DOCKETED

Docket Number:	23-AFC-02
Project Title:	Elmore North Geothermal Project (ENGP)
TN #:	259433
Document Title:	Michael McKibben Comments - Water use assessments for docket number 23-AFC-02
Description:	N/A
Filer:	System
Organization:	Michael McKibben
Submitter Role:	Public
Submission Date:	10/2/2024 5:01:27 PM
Docketed Date:	10/3/2024

Comment Received From: Michael McKibben
Submitted On: 10/2/2024
Docket Number: 23-AFC-02

Water use assessments for docket number 23-AFC-02

Dear CEC:
Attached is our recently published estimate of water use for geothermal and lithium development in the Salton Sea KGRA. We estimate that water demand for currently proposed geothermal production and lithium extraction facilities only accounts for Ã¢Ë†Â¼4% of the historical water supply in the region. Regional water allocation will be more impacted by the proposed cuts to the regions water allocation from the Colorado River between now and 2050 than by expansion of geothermal production with associated lithium extraction.
Mike
Michael A. McKibben, Ph.D.
Research Professor
Dept. of Earth & Planetary Sciences
University of California, Riverside CA 92521
LinkedIn: https://www.linkedin.com/in/michael-mckibben-1012b69/

Additional submitted attachment is included below.

ENVIRONMENTAL RESEARCH
LETTERS

LETTER • OPEN ACCESS

Impact of geothermal expansion and lithium extraction in the Salton Sea known geothermal resource area (SS-KGRA) on local water resources

To cite this article: Margaret M Busse *et al* 2024 *Environ. Res. Lett.* **19** 104011

ENVIRONMENTAL RESEARCH
LETTERS

CrossMark

OPEN ACCESS

RECEIVED
30 April 2024

REVISED
30 July 2024

ACCEPTED FOR PUBLICATION
2 August 2024

PUBLISHED
6 September 2024

LETTER

Impact of geothermal expansion and lithium extraction in the Salton Sea known geothermal resource area (SS-KGRA) on local water resources

Margaret M Busse[1,4], **Michael A McKibben**[2], **William Stringfellow**[3], **Patrick Dobson**[3] and **Jennifer R Stokes-Draut**[4,*]

[1] Department of Mechanical Engineering, Pennsylvania State University, University Park, PA, United States of America
[2] Earth and Planetary Sciences Department, University of California, Riverside, Riverside, CA, United States of America
[3] Earth and Environmental Sciences Area, Lawrence Berkeley National Laboratory, Berkeley, CA, United States of America
[4] Energy Technologies Area, Lawrence Berkeley National Laboratory, Berkeley, CA, United States of America
[*] Author to whom any correspondence should be addressed.

E-mail: jstokesdraut@lbl.gov

Keywords: flash geothermal, direct lithium extraction, Salton Sea, known geothermal resource area

Supplementary material for this article is available online

Abstract

Saline brines currently being brought to the surface to produce geothermal energy in the Salton Sea region of California contain high concentrations of lithium that could potentially be extracted before the brine is reinjected back into the geothermal reservoir. This would create a new supply chain of domestically sourced lithium for the United States to produce lithium-based batteries that will help drive the transition to a renewable-based energy grid. Plans to expand geothermal production along with lithium extraction are being considered in the Salton Sea known geothermal resource area. We discuss water availability and quality issues and potential concerns about water pollution associated with this geothermal expansion and lithium production in the context of potential future restrictions on water extractions from the Colorado River Basin. We estimate that water demand for currently proposed geothermal production and lithium extraction facilities only accounts for ∼4% of the historical water supply in the region. Regional water allocation will be more impacted by the proposed cuts to the region's water allocation from the Colorado River between now and 2050 than by expansion of geothermal production with associated lithium extraction. Accurately planning for water needs in the future will require more specific information about water demands of the lithium extraction and refining processes.

1. Introduction

The transition to a renewable-based electricity grid depends on advancements in energy storage. Short-term storage and electric vehicles currently depend on lithium-based batteries. The need for additional storage is driving the U.S. and state governments to invest heavily in a domestic supply chain for battery-grade lithium [1]. Domestic supplies of brine-hosted lithium have been identified in two arid, water constrained regions—Western Nevada and Salton Sea known geothermal resource area (SS-KGRA). The SS-KGRA, the focus of this work, is a region within Imperial County, California near the South shore of the Salton Sea. Water for irrigation, municipal use, and geothermal energy production is supplied to the region through canals conveying water sourced from the Colorado River (figure 1).

Lithium resources in geothermal brines in the SS-KGRA are significant. Dobson *et al* estimates the minimum total capacity of the lithium resource to be 4.1 million tonnes (t) of lithium carbonate equivalent (LCE), with the potential to produce 115 000 t per year [2]. For context, models of U.S. annual lithium demand projections into 2050 vary widely from 9800–228 200 t [3]. This provides a synergistic opportunity to produce lithium while expanding clean energy production,

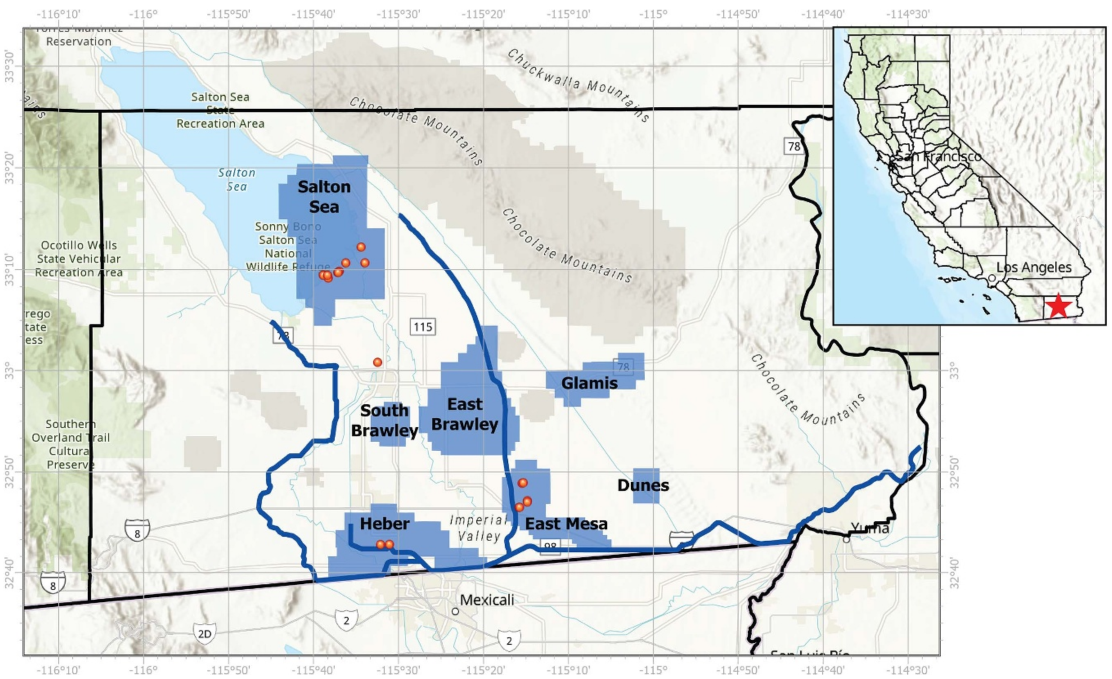

Figure 1. Map of the KGRAs (blue areas), geothermal power plants (red dots), Colorado River (dashed light blue line), and the major water canals (solid blue lines) located in Imperial County, California with inset showing the location of Imperial County in California shown with a red star.

making geothermal energy production more cost competitive, and avoiding constructing additional wells or withdrawing additional brine.

Water is a non-negligible input into energy production and conversion processes, even for an electricity grid that relies heavily on renewable energy. The amount of water required varies, making energy type and technology choice important drivers of regional water use [4].

Obtaining the raw materials for battery production also has important water implications. Conventional methods of extracting and processing lithium from subterranean brines and ore deposits are water intensive. The impact of the water use required for energy and lithium production depends on whether the source of the water is saline groundwater or freshwater and whether the water is withdrawn or consumed (definitions provided in the supplementary information (SI)).

Since the SS-KGRA is in a desert environment with limited access to freshwater, understanding how growth in geothermal production and lithium extraction will impact water consumption in this region is critical. Herein, we use publicly available resources to quantify and contextualize the water availability, water quality, and water demands in the SS-KGRA with and without expanded geothermal production and lithium extraction. The paper was adapted and updated from an extensive report that independently assessed potential challenges to expanding these industries in the SS-KGRA (chapter 7) [2].

2. Context of water in the SS-KGRA

The SS-KGRA, located in Imperial Valley, is in the Southeast corner of California in a closed basin that is adjacent to the Colorado River watershed. Availability of water in the region is impacted by both water quality and quantity. There are four water resources in the region that could be relevant to decisions about geothermal and lithium production: local surface water, Colorado River water, groundwater, and the Salton Sea.

2.1. Local surface water

The SS-KGRA is in an arid, desert climate that receives less than 8 cm of average annual rainfall. Average summer temperatures exceed 38 degrees Celsius. Two rivers, the New and Alamo Rivers, flow into and recharge the Salton Sea. These rivers function more as drains for potentially contaminated agricultural runoff than as channels for freshwater. Limited rainfall and contamination in local channels prevent local surface water resources from being used by the geothermal or lithium extraction industries. Local surface water is not considered in long-term water resource planning for industry or municipal use in the region [5].

2.2. Colorado river water

The Imperial Valley is an agricultural region that relies exclusively on water conveyed from the Colorado River by the Imperial Irrigation District

(IID). The IID withdraws water near the Imperial Dam, located about seventy miles Southeast of the SS-KGRA and twenty miles North of Yuma, Arizona. Irrigation typically consumes well over 90% of the IID's water supplies. In 2022, 94% of IID water was used for agriculture, 2% for municipal potable uses, and 4% was used for commercial and industrial purposes, including geothermal energy production.

The IID's legal right to Colorado River water was established prior to and codified in the 1922 Colorado River Compact [6]. The original Compact specified that 20.3 cubic kilometers (km^3) be allocated for use in seven U.S. states. The 'Upper Basin' states (Colorado, Wyoming, Utah, and New Mexico) were granted half the water, and the 'Lower Basin' states (California, Arizona, and Nevada) were granted the remainder. The Compact was subsequently revised to allocate 1.9 km^3 to Mexico by reducing the allotments to the Upper and Lower Basins to 9.5 km^3 each. Since 1944, California has held an annual right to the largest share, 5.4 km^3, from which the IID has an annual right to 3.2 km^3. Their senior water right requires other users to reduce water consumption when a shortage occurs before the IID has to reduce usage.

Water allocations in the Compact were established using a period of unusually heavy rainfall. Thus, the assumption that 20 km^3 of water will be available each year has proven overly optimistic. Recently, the Colorado River watershed has been experiencing a long-term drought. Annual withdrawals in both Basins have decreased to 16 km^3. While below the legal allocations, withdrawals still exceed the approximately 13.6 km^3 of annual average flow currently available. This over-withdrawal has caused declining water levels in reservoirs along the Colorado River, particularly in the Lower Basin states.

Lake Mead and Lake Powell are two key reservoirs that store water for the Lower Basin states. In June 2022, the U.S. Bureau of Reclamation (USBR), the watermaster for the Colorado River, raised concerns about water levels in both reservoirs. The USBR wants to ensure reservoir water is maintained at a level that supports hydropower production (the 'minimum power pool' elevation) and downstream flow from the dam (the 'dead pool' elevation) [7] (details in SI).

To prevent the loss of hydropower production, the USBR asked the states in the Colorado River Basin to revise their most recent drought contingency plan adopted in 2019. USBR requested a voluntary agreement to reduce water withdrawals by 2.5–4.9 km^3 per year or up to one-third of current allocations by a 31 January 2023 deadline. If the deadline was not met, the USBR could impose new water use requirements [7, 8]. The fear of federal action led to proposals for reducing water use in the Basin.

Six of the seven Colorado River Basin states met the deadline and jointly proposed a plan to reduce water use by 20%, with the largest cuts from Arizona and California [8]. This plan asked California to cut their annual water use by 1.2 km^3; California did not agree. California offered a competing proposal that formalized voluntary 10% cuts they instituted in October 2022 [9, 10]. IID reduced their water use proportionally. California's plan claimed Basin-wide water use reductions of 10% to 20% but, unlike the six-state proposal, did not account for the approximately 2 km^3 lost each year due to evaporation and leaks in conveyance systems. Negotiations continued until all states reached a collective voluntary agreement in May 2023, which reduces water demand in the Lower Basin states by 14%, with each state taking a proportional share of the shortage. Therefore, California is required to make the largest volume of demand reductions.

The USBR released a draft revised supplementary environmental impact statement in October 2023 concluding that, given the wet winter of 2023, the state's plan could protect Lake Powell and Lake Mead from reaching their power pool elevations by 2026 but recommended additional modeling before they issue the final statement [11]. The impacts of these negotiations will be temporary because they amend a drought contingency plan that is set to expire in 2026. New negotiations will establish longer-term water allocation agreements between the states. Regardless of the IID's senior water right, future water availability may be more constrained in the Imperial Valley, though the magnitude of these constraints is currently uncertain.

2.3. Groundwater

Statewide, groundwater supplies 40% of California's water supply in a typical year [12]. However, groundwater is not an important water source in the SS-KGRA. A large groundwater Basin underlies a 4900 km^2 area of the Imperial Valley region [13], but it is not used for agricultural, municipal, or industrial purposes due to poor groundwater quality. The primary source of recharge water for local aquifers is unlined agricultural canals [14] and irrigation recharge [15].

The contaminated groundwater does not interact hydraulicly with other important water sources in the SS-KGRA. The shallow aquifers are hydraulicly separated from the Salton Sea by deposits with low transmissivities (less than 2.4 m^3 per day per meter). Other low-permeability aquitards restrict flow between the shallow aquifers and the much deeper geothermal reservoirs. Typical groundwater wells are less than 610 m deep [15]. The deepest active production well in the SS-KGRA (Elmore 16) is 2800 m deep, and the deepest active injection well (River Ranch 3) is 2900 m deep.

2.4. Salton Sea

The Salton Sea (and its precursor, Lake Cahuilla) has alternated between being a large inland lake and a dry sink throughout the past several million years. The Salton Sea that exists today was created in 1905 when levees built to transport irrigation water from the Colorado River collapsed. Vast quantities of water flooded the Colorado Desert and pooled at its lowest point, the Salton Sink. Since then, the Salton Sea has been sustained largely, though not exclusively, through agricultural runoff [16].

This was impacted in 2003 when cities in Southern California negotiated with IID to obtain water transfers (0.62 km^3) to alleviate water shortages during a drought. To provide this water, IID implemented new conservation measures on farms in their service area, which reduced runoff to the Salton Sea. Mitigation water was transported to the sea to offset the loss of this inflow until the end of 2017 [17]. Since then, water levels in the sea have been falling and its areal extent has been shrinking [17, 18]. This has led to the death of fish and birds in the area, increased dust (containing toxic constituents from the drying seabed), and concentrated salinity and toxic constituents in the remaining water of the Salton Sea [17].

While the Salton Sea is an important water body in the region that serves as ecological habitat [19] and, as it dries out, as a source of air pollution [20], it is not a viable water source for municipal, industrial, or agricultural activities in the SS-KGRA. The water is highly saline and contains other contaminants that preclude its use.

3. Methods

3.1. Regional geothermal production

Current geothermal facilities in the SS-KGRA include those operated by CalEnergy (Del Ranch (A.W. Hoch), Vulcan, J.J. Elmore, Salton Sea Units 1–5, and J.M. Leathers) and Cyrq (Hudson Ranch). Geothermal expansion and lithium production processes were proposed and later cancelled by Hudson Ranch II/Simbol [21]. Instead, Energy Source Minerals (ESM) is planning to extract the lithium from the brine at the existing Hudson Ranch plant. New geothermal power plants with lithium recovery systems have been proposed for implementation over the next few years by Berkshire Hathaway renewables (BHER) (Black Rock, Elmore North, and Morton Bay) [14, 22, 23], and Controlled Thermal Resources (CTR) (seven facilities). The geothermal plants in the SS-KGRA are flash steam plants (description in SI).

3.2. Geothermal water use

In addition to the geothermal brine used to produce energy, freshwater is needed to operate geothermal energy production facilities. Cooling towers use 70% of the freshwater as makeup water to offset water lost through evaporation in the hot SS-KGRA region [14, 21]. Freshwater is also used to dilute the brine for onsite processing and before reinjection to prevent certain constituents from precipitating and plugging the injection well. In the SS-KGRA, freshwater is purchased from the IID and treated on-site, if needed, to achieve the water quality required for each process.

In 2012, the IID reported water use estimates for all geothermal facilities in Imperial County, based on self-reported data [5]. Using this historic data, we estimate geothermal facilities in the SS-KGRA purchase an average of 19 700 m^3 each year for every MW of net generation capacity. The capacity factors of these facilities range between 74%–100% [2]. The water demand of individual facilities ranges widely from 493–39 500 m^3 per MW annually. The variability is a result of the amount of steam condensate that is reused at each facility as well as the water consuming processes on site.

A detailed breakdown of annual water use was publicly available for only the formerly proposed Hudson Ranch Power II facility. It was to have a geothermal capacity of 50 MW and use 3.45 million m^3 of cooling water. Steam condensate from the plant would be used to supply the majority of this water, but an additional 54 000 m^3 per year of makeup water would be needed from the IID. An additional 1.36 million m^3 of IID water would be needed for brine dilution water, 25 000 m^3 for freshwater pond evaporation, and 14 800 m^3 for miscellaneous uses [21]. Overall operation would have required approximately 1.48 million m^3 per year (29 600 m^3 per MW per year) from IID.

Newly proposed geothermal facilities in the region from BHER have site-specific plans for meeting these water needs. Morton Bay Geothermal (157 MW capacity) proposes using 6.86 million m^3 of freshwater per year (43 172/MW), 50% of their water needs [14]. Black Rock Geothermal (87 MW) proposes to use 1.39 million m^3 of freshwater per year (15 912 m MW^{-3}) or 20% of their water needs [22]. Elmore North Geothermal (157 MW) plans to use 7.99 million m^{-3} per year of freshwater (54 273 m MW^{-3}) for 50% of their demand [23]. In all three cases, the remaining water will come from condensed steam. Additional water will be required at each of these facilities for start-up, fire protection, and maintenance. Two of these new plants have water use per MW capacity greater than the range reported in the 2012 integrated regional management plan (IRWMP) [24].

3.3. Lithium extraction

Water requirements for producing lithium carbonate and lithium hydroxide monohydrate for use in batteries depend on the method used to concentrate and extract the lithium. Typically, lithium is obtained by

1) mining lithium from spodumene ore [25] or by 2) pumping highly saline groundwater (subterranean brine) from shallow wells (typically between 1.5–60 m deep) and allowing it to evaporate from ponds at the surface [26]. A recent study reported that, though extracting lithium from subterranean brines consumes large volumes of high-salinity brines, ore-based methods consume more freshwater per t of lithium product ($LiOH•H_2O$) produced [27].

Lithium mining from spodumene occurs internationally but does not currently occur in the U.S., though there is a proposal to reopen a former spodumene mine in North Carolina. There is one operating mine in Nevada that extracts lithium from brines through evaporation. Two new claystone mines are also planned in Nevada. In the SS-KGRA, lithium will be extracted using a more novel method known as direct lithium extraction (DLE).

A recent review of the literature on environmental impacts of lithium production noted that very little quantitative information is available on freshwater needs for DLE, especially for pre- and post-processing steps [26]. We were unable to obtain detailed information about the specific DLE methods facilities in the SS-KGRA plan to use or how water would be used for lithium extraction. We understand that the proposed lithium extraction method in most SS-KGRA facilities involves, or is similar to, ion exchange. We developed a summary of proposed lithium extraction processes and associated water usage based on an ESM lithium adsorption and recovery patent [28], lithium extraction and processing from Smackover brines [29], and our extrapolation based on unit processes (figure S2; 'S' refers to a figure in the SI). We expect water use in the SS-KGRA to be similar, but it could vary depending on the design of the process. Without more information on the precise processes being used, we were unable to independently verify the projections for water use at future facilities or identify opportunities to reduce water consumption.

Initial planning documents indicate these facilities are implementing at least some onsite water recycling. These processes are expected to be housed in new facilities, separate from the energy production facility. The energy for these facilities is expected to come from the geothermal energy production, and therefore no additional water use was included for energy production at lithium facilities.

3.4. Regional impact assessment

Future water usage for geothermal energy was calculated based on an average water usage per MW for the existing facilities in the SS-KGRA [5]. Lithium extraction was based on low, medium, and high-water usage estimates per LCE production from the literature. [Note: Sources report lithium production as the mass of lithium metal, the mass of lithium hydroxide, or the mass of lithium carbonate. We converted these data to LCE to consistently compare masses of lithium reported in different forms.] Low-, medium-, and high-water use estimates were calculated based on:

- Production projections for reported geothermal capacity for Simbol/Hudson Ranch (321 t LCE/MWe; this project, while canceled, still reflects potential performance) [21], as well as the current Hell's Kitchen (371 LCE/MWe) [30], and ATLiS/Hudson Ranch I (381 LCE/MWe) [31], respectively;
- Water use estimates for lithium production (not including geothermal operations) from BHER (189 m^3 t^{-1} LCE) [32], ESM (247 m^3 t^{-1} LCE) [32], and CTR (548 m^3 t^{-1} LCE) [33], respectively.

We developed three geothermal capacity expansion scenarios as described below:

- Existing capacity: 400 MW of existing geothermal in the region and the LCE that could be extracted from the associated brines—150 000 t LCE for the medium LCE production case (low = 130 000 t; high = 150 000 t) The medium and high case results round to the same value;
- Projected (3–4 year) geothermal capacity: an additional 520 MW of planned expansion (920 MW in total)—340 000 t LCE for the medium LCE production case (low = 290 000 t; high = 350 000 t); and
- Maximum possible capacity: an additional 2030 MW capacity from the projected scenario to meet the estimated maximum geothermal capacity in the region of 2950 MW [32]—11 00 000 t LCE for the medium LCE production case (low = 950 000 t; high = 11 00 000 t). The medium and high case results round to the same value. We use this scenario to project an upper bound on impact.

We estimated water demands for these three geothermal and lithium expansion scenarios.

4. Results and discussion

4.1. Geothermal water usage

Figure 2 compares the estimated water consumption (m MW^{-3}) for energy production from geothermal plants in the SS-KGRA to water consumption for other geothermal energy [34] and other sources of electricity generation [35]. The only data for existing plants was published in a regional water planning document over a decade ago [5]. Estimates for proposed plants are calculated using the nameplate capacity, water consumption data provided by the potential operator in planning documents, and assume plants are operated continuously [14, 22, 23]. Most energy in California comes from noncombustible renewables, crude oil, natural gas and nuclear sources. Coal is included for comparison but, based on the 2020 California energy profile, California does not use coal to produce energy.

The SS-KGRA geothermal plants are flash plants, which can consume more water than other modes of generation (figure 2). The higher water consumption is due to evaporation of high temperature steam being pulled from the wells, a unique feature of flash plants. Losses can vary between 14%–33% of produced geothermal fluid at flash plants [34]. Water usage for flash plants in figure 2 is divided into operational freshwater (blue) and losses of geothermal brine due to evaporation, drift, and blowdown (yellow).

Operational freshwater usage at the SS-KGRA facilities exceeds typical values at geothermal flash plants. There are several possible reasons for this discrepancy. First, the estimates for SS-KGRA facilities include water used for construction of facilities, not just operation (details in the SI). Further, these values were facility-reported during review and approval of the facilities and may not reflect actual on-site operational usage. Higher water consumption may be due to the arid region or other uses of freshwater at these facilities that were not considered in other studies. As a result, the SS-KGRA estimates may be conservative.

4.2. Lithium extraction water usage

As previously mentioned, lithium is commonly produced through methods of lithium ore mining and lithium brine evaporation, which differ from the DLE extraction processes being proposed for the SS-KGRA. Figure 3 shows a comparison of the documented water use for these lithium extraction methods. The values were adapted from literature sources, including DLE marketing materials, and were not independently verified. Total water use for lithium brine evaporation ponds is based on operations in Chile [36]. Most of the water used for brine evaporation in Chile is considered fossil or relic water, defined as water that entered the Basin more than 65 years ago [37]. The estimates of the freshwater use represent the median of observed freshwater for brine evaporation ponds in Chile (4% of total water use; visually approximated from a graph). Lithium ore mining is based on mining operations in Australia and conversion in China [36].

Kelly *et al* conducted a life-cycle assessment for traditional lithium extraction and conversion processes using brine evaporation and ore-based methods. This study quantified all freshwater used at lithium facilities themselves as well as water associated with the supply chain (e.g. producing electricity used at the facility; producing fuels used to transport materials). It estimated that producing lithium carbonate from brine evaporation ponds required 15–32 m^3 t^{-1} of LCE. For lithium ore mining, the freshwater use was estimated to be 76 m^3 t^{-1} of LCE [27]. These values are similar to data reported in figure 3 indicating most water use occurs in the operation phase. The supply chain does not appear to contribute significantly to water use for traditional lithium processes.

Schenker *et al* produced a parameterized life cycle inventory model with site-specific conditions for the Salton Sea and reported water use for brine pre-treatment (not quantified), lithium desorption (2348 m^3 t^{-1} Li_2CO_3) and regeneration the ion exchanger (2583 m^3 t^{-1} Li_2CO_3). They suggest water use could be reduced for the desorption process if partially supplied by other processes at a lithium production facility such as reverse osmosis and the triple evaporator [38], but this is still significantly more water use than the values reported by companies in the Salton Sea. Recently, Halkes *et al* summarized challenges and opportunities for assessing water use for lithium production from salar deposits, and they indicate that DLE processes are expected to consume more freshwater than evaporative ponds [39], which is consistent with figure 3.

We obtained a few facility-wide estimates for water usage for lithium extraction in the SS-KGRA. Data for the ESM Hudson Ranch facility and BHER were reported in the Report of the Blue Ribbon Commission on Lithium Extraction in California [40]. Data from CTR was obtained from a recent filing with the Imperial County Planning Commission on their Hell's Kitchen Power and Lithium project [33]. The ESM data is based on the water allocation requested from IID for their facility and is inclusive of all water needs at the site. In a public meeting in May 2023, ESM indicated that they expect the actual water use to be as much as a third lower than the value shown. Since this claim has not been documented in writing to our knowledge, we have not used adjusted our estimates based on this statement.

4.3. Regional impact

Figure 4 summarizes the regional water needs for expanding geothermal energy production in the SS-KGRA and the lithium production possible from the brines extracted to operate these plants based on the data sources and assumptions discussed previously. The red line indicates water being used or already allocated in the region currently. The low-, medium-, and high-projections for water requirements based on existing or allocated LCE capacity captures the water needed to extract lithium from the brines that are already being brought to the surface for geothermal production.

We estimate about 0.008 km^3 of freshwater is used annually for the existing 400 MW of geothermal capacity and 0.0042 km^3 has been allocated by IID to ESM for their lithium extraction facility to produce 17 000 t of LCE. Assuming future geothermal and lithium processes use water at similar rates as these facilities (i.e. approximately 20 000 m^3 per MW and 246 m^3 t^{-1} of LCE, respectively), we estimate that water needed for geothermal production and lithium extraction in

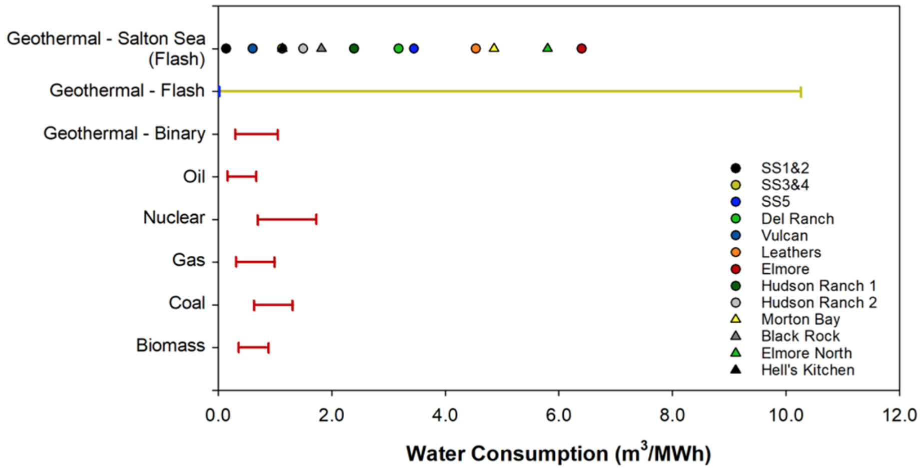

Figure 2. Water usage from different energy sources adapted from Childress *et al* to include general estimates for geothermal power plants from Clark *et al* and IID water demand from geothermal plants in the SS-KGRA for construction and operation [6, 14, 21, 22, 34, 35]. Water consumption for flash plants labeled geothermal—flash is divided into operational freshwater (blue) and losses of geothermal brine due to evaporation, drift, and blowdown (yellow) based on guidance in Clark *et al* [34]. The estimates from Clark *et al* are life cycle estimates of U.S.-based plants [34]. Adapted from [2]. CC BY 4.0.

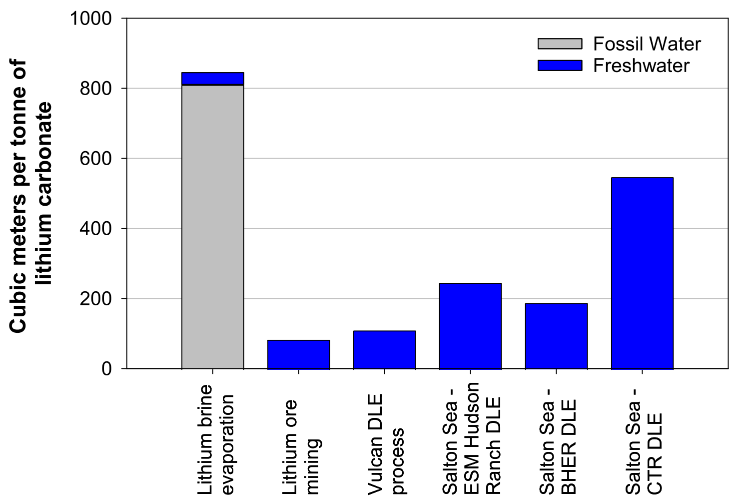

Figure 3. Water usage for different lithium extraction methods [32, 33, 37, 38]. DLE is direct lithium extraction. ESM is Energy Source Materials. BHER is Berkshire Hathaway Energy Renewables. (*Source*: adapted from Dobson *et al* [2] to include new data from Controlled Thermal Resources (CTR) [33]. Personal communication with CTR indicates this may overestimate water use but this has not been verified). Adapted from [2]. CC BY 4.0.

the region will increase by 2.3× if the projected capacity is achieved with medium level water use estimates for LCE. As shown in figure 4, the combination of a low-LCE production rate per MWh such as that previously proposed by Simbol/Hudson Ranch and high-water use from a LCE production process like that proposed by CTR would lead to drastic increases in water use.

Though this indicates significant growth, the water needs for geothermal and lithium production in the SS-KGRA are modest compared to total water use in the area. The water consumed for the planned (3–4 year) geothermal expansion with medium lithium production and medium water use represents about 4% of IIDs current water right and is similar to the volume of water needed to irrigate 4270 ha in the region.

In a water-constrained region, however, any increase in planned water use should be carefully considered. The Imperial Valley's IRWMP projected water needs for renewable energy production, including geothermal energy, in the region to be 0.178 km^3 per year [24]. This projection includes all of the Imperial Valley, not just the SS-KGRA. This may be sufficient to accommodate the expected growth of geothermal but not the associated lithium production (water needs for new facility construction and ongoing operations).

Lithium production would be categorized as new non-agricultural water needs in IID's current water

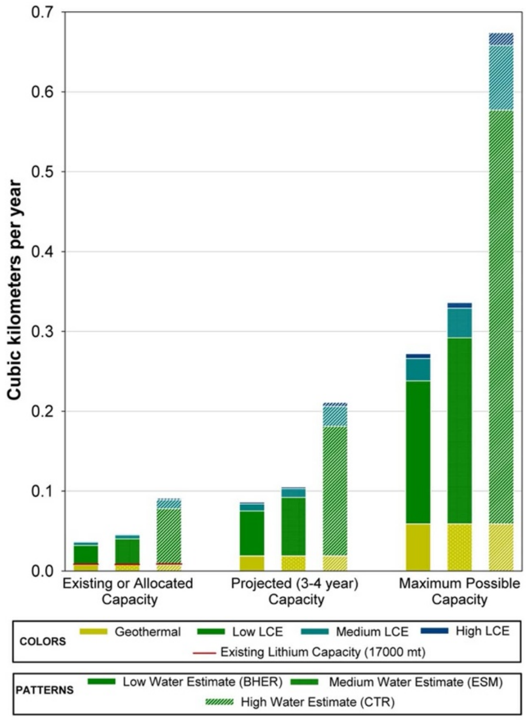

Figure 4. Current allocated and projected water needs for geothermal energy and lithium production in the SS-KGRA. The red bold line in the existing or allocated bar indicates allocations that have already been made for lithium capacity. Low-, medium-, and high-water usage estimates for LCE are based on proposed processes at Simbol/Hudson Ranch [21], Hell's Kitchen [30], and ATLiS/Hudson Ranch I [31], respectively. The projections assume lithium is extracted from all geothermal brines extracted under existing, projected, and maximum possible conditions. Low-, medium-, and high-water consumption processes were established from BHER, ESM [32], and CTR [33], respectively.

supply plan [5], for which IID has allocated up to 0.031 km^3 per year. IID has already allocated 0.0057 km^3 of this volume to new projects, 75% of which will be used by ESM's Hudson Ranch lithium facility. The remaining 0.025 km^3 could produce about 115 000 t of LCE but is insufficient to meet regional goals for expanded lithium production. In an email exchange, the IID indicated that the current water supply plan has not been updated to account for the potential water demands of lithium extraction because they have not used the original allocation yet [41]. IID indicated they can expand this allocation if needed through conservation on agricultural lands and have indicated so in recent CEC filings.

4.4. Future water availability

Projecting future water availability in the SS-KGRA is complicated by the extended drought in the Colorado River Basin. Water availability in the Imperial Valley will be impacted by the recent agreement reducing California's allocations from the Colorado River by 14% and could be further reduced by a subsequent federal action if the proposed cuts are insufficient and/or by a future drought contingency plan negotiated for the river. A new drought plan must be adopted by 2026 [42].

In the SI, we discuss potential impacts of projected cuts to the Colorado River allocation, and the combined impact with projected geothermal expansion and lithium extraction, compared to 2010 and current uses (figure S3). Expanding geothermal energy and lithium production in the SS-KGRA to currently proposed levels will have a modest impact on overall water consumption in the Imperial Valley (4% of historical supply). However, it is important to note that water demand for lithium extraction is appreciable, representing an additional 5–6 times the freshwater requirements of geothermal energy production alone from a given volume of brine based on published estimates for facilities planned in the SS-KGRA region. However, water consumption will be significantly less than that required for conventional approaches to lithium removal from brines such as evaporation ponds.

These water reductions are significant and will have measurable impacts on the economy and communities in the region, both positive and negative. In an agricultural region like the SS-KGRA, crop production, employment, and municipal populations and demographics could all change substantially.

Some of those changes may impact the Salton Sea itself. The shrinking of the Salton Sea that has led to current environmental crisis is largely attributed to water conservation on agricultural land associated with the transfer of 617 million m^3 to Southern California cities. Depending on how water shortages are distributed in the Colorado River Basin, if geothermal and lithium production water demands increase, water available for agriculture could be between 18% and 48% lower than it was in 2010. Such reductions in irrigation could have meaningful consequences for the health of the Salton Sea by further reducing inflows. The future water projections assume additional conservation of at least a similar magnitude and possibly up to 18.5 km^3. Ongoing efforts to protect the Salton Sea should consider these potential changes to water runoff from irrigation.

5. Conclusions

The more influential factor on regional water allocation between now and 2050 is the proposed cuts to IID's water allocation from the Colorado River. Cuts have been proposed as high as 40%, though only a 14% reduction has currently been agreed upon. If these aggressive restrictions are implemented, the water consumption associated with the planned geothermal expansion and associated lithium extraction would only represent 7% of the regions' water use (figure S3). However, the cumulative effect of the potential 40% regional water cuts and expansion of these industries to full capacity would reduce water available to agriculture by almost 50% compared to 2010 consumption. It is not expected to impact the availability or quality of water used for human consumption.

In this water constrained environment, however, new water demands must be carefully evaluated and transparently communicated. Communities will inevitably feel the cumulative effects of the water availability constraints and increased demands. As highlighted in Blair *et al* [43], the impact of lithium extraction on water and society will differ based on region, mode of extraction, and the scope of the water analysis.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Acknowledgments

The authors would like to acknowledge the support from Mary Kay Camarillo (University of the Pacific), Dev Millstein (Lawrence Berkeley National Laboratory), and Margaret Slattery (University of California, Davis). These team members provided critical feedback and insight during the project. We would also like to acknowledge Jeremy Snyder and Diana Swantek for their help with graphics and Sahar El Abbadi (Lawrence Berkeley National Laboratory) for feedback on the text describing current water allocations in the Colorado River.

We also thank Cyrq/Energy Source Minerals for giving us a tour of the Featherstone plant and answering questions from our team. We also appreciate Jon Trujillo, Billy Thomas, and Jonathan Weisgall from Berkshire Hathaway Energy Renewables/CalEnergy for providing critical contextual information and responding to our many queries.

Funding

This work is supported by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy (EERE), Geothermal Technologies Office, under Award Number DE-AC02–05CH11231 with Lawrence Berkeley National Laboratory.

ORCID iDs

Margaret M Busse https://orcid.org/0000-0002-4256-5187
Michael A McKibben https://orcid.org/0000-0002-9511-2579
William Stringfellow https://orcid.org/0000-0003-3189-5604
Patrick Dobson https://orcid.org/0000-0001-5031-8592
Jennifer R Stokes-Draut https://orcid.org/0000-0003-0240-1361

References

[1] The White House FACT SHEET: Biden-Harris administration driving U.S. battery manufacturing and good-paying jobs (The White House) (available at: www.whitehouse.gov/briefing-room/statements-releases/2022/10/19/fact-sheet-biden-harris-administration-driving-u-s-battery-manufacturing-and-good-paying-jobs/) (Accessed 30 May 2023)
[2] Dobson P *et al* 2023 Characterizing the geothermal lithium resource at the Salton Sea LBNL Report LBNL-2001557 (available at: https://escholarship.org/uc/item/4x8868mf) (Accessed 28 November 2023)
[3] Miatto A, Wolfram P, Reck B K and Graedel T E 2021 Uncertain future of American lithium: a perspective until 2050 *Environ. Sci. Technol.* **55** 16184–94
[4] Spang E S, Moomaw W R, Gallagher K S, Kirshen P H and Marks D H 2014 The water consumption of energy production: an international comparison *Environ. Res. Lett.* **9** 105002
[5] GEI Consultants, Inc 2012 *Supply, Demand, and Water Budget* (Imperial Irrigation District)
[6] City of Santa Fe 1922 *Colorado River Compact, 1922* (available at: https://digitalrepository.unm.edu/uc_rio_chama/75?utm_source=digitalrepository.unm.edu%2Fuc_rio_chama%2F75&utm_medium=PDF&utm_campaign=PDFCoverPages)
[7] Bureau of Reclamation 2023 Near-term Colorado River operations draft supplemental environmental impact statement (U.S. Department of the Interior) (available at: www.usbr.gov/ColoradoRiverBasin/documents/NearTermColoradoRiverOperations/20230400-Near-termColoradoRiverOperations-DraftEIS-508.pdf)
[8] Partlow J 2023 Six of the Colorado River states agreed on water cuts. California did not (The Washington Post (available at: www.washingtonpost.com/climate-environment/2023/01/31/colorado-river-states-water-cuts-agreement/) (Accessed 11 October 2023)
[9] Becker R 2022 California offers to reduce use of Colorado River water (CalMatters) (available at: https://calmatters.org/environment/2022/10/california-colorado-river-water/) (Accessed 11 October 2023)
[10] Ronayne K and Naishadham S and The Associated Press 2023 California has a plan for cutting Colorado River use. It involves pretending water doesn't evaporate (available at: https://fortune.com/2023/02/01/california-plan-cutting-colorado-river-use-involves-pretending-water-not-evaporate/) (Accessed 28 November 2023)
[11] USBR Supplemental environmental impact statement for near-term Colorado River operations *Colorado River Basin* (available at: www.usbr.gov/ColoradoRiverBasin/interimguidelines/seis/index.html) (Accessed 28 November 2023)
[12] SWRCB 2020 Groundwater fact sheet
[13] California Department of Water Resources 2004 Imperial Valley groundwater Basin *California's Groundwater Bulletin 118* (available at: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Groundwater-Management/Bulletin-118/Files/2003-Basin-Descriptions/7_030_ImperialValley.pdf)
[14] Morton Bay Geothermal LLC 2023 Morton Bay geothermal project application for certification volume 1 (BHER) (available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=249723&DocumentContentId=84361)

[15] Tompson A *et al* 2008 Groundwater availability within the Salton Sea Basin final report LLNL-TR-400426, 932394 (https://doi.org/10.2172/932394)
[16] Hanak E *et al* 2018 California's water: the Colorado River (PPIC)
[17] Fogel M L and Schwabe K 2021 Framing the Crisis unfolding at the Salton Sea *Crisis at the Salton Sea: The Vital Role of Science* (University of California Riverside) pp 20–27 (available at: https://eartharxiv.org/repository/view/2113/)
[18] Yi F and Qiu P 2023 Water resource surveillance for the Salton Sea in California by adaptive sequential monitoring of its landsat images *J. Agric. Biol. Environ. Stat.* **28** 549–63
[19] Nye J W, Aronson E, Jenerette G D and Fogel M L 2021 Ecosystems of the Salton Sea and surrounding environments *Crisis at the Salton Sea: The Vital Role of Science* (University of California Riverside) pp 56–65 (available at: https://eartharxiv.org/repository/view/2113/)
[20] Bahreini R, Porter W and Aronson E 2021 Particulate matter, pollutant gases and atmospheric transport at the Salton Sea *Crisis at the Salton Sea: The Vital Role of Science* (University of California Riverside) pp 46–55 (available at: https://eartharxiv.org/repository/view/2113/)
[21] Energy Source 2012 Hudson Ranch power II geothermal plant/Simbol Calipatria II plant project *Draft EIR* (Imperial County)
[22] Black Rock Geothermal LLC 2023 Black rock geothermal project application for certification volume 1 (BHER) (available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=249752&DocumentContentId=84391)
[23] Elmore North Geothermal LLC 2023 Elmore North geothermal project application for certification volume 1 (BHER) (available at: https://efiling.energy.ca.gov/GetDocument.aspx?tn=249737&DocumentContentId=84377)
[24] GEI Consultants 2014 Imperial Valley integrated regional water management plan (Imperial Irrigation District) (available at: https://www.iid.com/water/water-supply/water-plans/imperial-integrated-regional-water-management-plan)
[25] Wietelmann U and Steinbild M 2014 *Ullmann's Encyclopedia of Industrial Chemistry* 7th edn (Wiley-VCH Verlag GmbH & Co. KGaA)
[26] Vera M L, Torres W R, Galli C I, Chagnes A and Flexer V 2023 Environmental impact of direct lithium extraction from brines *Nat. Rev. Earth Environ.* **4** 149–65
[27] Kelly J C, Wang M, Dai Q and Winjobi O 2021 Energy, greenhouse gas, and water life cycle analysis of lithium carbonate and lithium hydroxide monohydrate from brine and ore resources and their use in lithium ion battery cathodes and lithium ion batteries *Resour. Conserv. Recycl.* **174** 105762
[28] Marston C R and Garska M J 2022 Process for selective adsorption and recovery of lithium from natural and synthetic brines
[29] Breuer R, Eccles R, Hunt T, Mielke E, Molnar R and Shikaze S 2021 Standard lithium Ltd preliminary economic assessment of Sw Arkansas lithium project (NORAM Engineering and Constructors Ltd)
[30] County of Imperial Hell's kitchen powerco 1 and lithiumco 1 project 2022 (available at: https://files.ceqanet.opr.ca.gov/277330-1/attachment/umqX2ZYUYgPDPnQmJ1zkDyRyVLAng5T8MBZGSmrgzFDiB8GLtk0M8WcbNQvXIZ8U6A4g_EZEGzbWm6l_0)
[31] Chambers Group, Inc. 2021 Draft environmental impact report for the energy source mineral atlis project Imperial County, California *Environmental Impact Report*
[32] Kaspereit D, Mann M, Sanyal S, Rickard B, Osborn W and Hulen J 2016 Updated conceptual model and reserve estimate for the Salton Sea geothermal field, Imperial Valley, California *Geotherm. Res. Counc. Trans.* **40** 57–66 (available at: https://www.researchgate.net/profile/Dennis-Kaspereit-2/publication/311766462_Updated_Conceptual_Model_and_Reserve_Estimate_for_the_Salton_Sea_Geothermal_Field_Imperial_Valley_California/links/5859698408aeabd9a58b47bc/Updated-Conceptual-Model-and-Reserve-Estimate-for-the-Salton-Sea-Geothermal-Field-Imperial-Valley-California.pdf)
[33] Controlled Thermal Resources, Inc 2024 Appeal #23-0004 of the December 13, 2023 *Planning commission decision's of approval for the Hell's kitchen power and lithium projects* (Imperial County Planning & Development Services Planning/Building)
[34] Clark C E, Harto C B, Sullivan J L and Wang M Q 2011 Water use in the development and operation of geothermal power plants ANL/EVS/R-10/5 (Argonne National Laboratory) (available at: https://publications.anl.gov/anlpubs/2010/09/67934.pdf)
[35] Childress A *et al* 2021 National alliance for water innovation (NAWI) technology roadmap: power sector
[36] Vulcan Energy 2021 Vulcan energy zero carbon lithium: industry-leading life cycle assessment results (Vulcan Energy)
[37] Moran B J, Boutt D F, McKnight S V, Jenckes J, Munk L A, Corkran D and Kirshen A 2022 Relic groundwater and prolonged drought confound interpretations of water sustainability and lithium extraction in arid lands *Earth's Future* **10** e2021EF002555
[38] Schenker V, Bayer P, Oberschelp C and Pfister S 2024 Is lithium from geothermal brines the sustainable solution for Li-ion batteries? *Renew. Sustain. Energy Rev.* **199** 114456
[39] Halkes R T, Hughes A, Wall F, Petavratzi E, Pell R and Lindsay J J 2024 Life cycle assessment and water use impacts of lithium production from salar deposits: challenges and opportunities *Resour. Conserv. Recycl.* **207** 107554
[40] Paz S *et al* 2022 Report of the Blue Ribbon Commission on lithium extraction in California CEC-300-2022-009-F (California Energy Commission)
[41] Shields T 2022 Personal Communication
[42] Flavelle C 2023 Biden administration proposes evenly cutting water allotments from Colorado River (The New York Times) (available at: www.nytimes.com/2023/04/11/climate/colorado-river-water-cuts-drought.html) (Accessed 12 October 2023)
[43] Blair J J A, Vineyard N, Mulvaney D, Cantor A, Sharbat A, Berry K, Bartholomew E and Ornelas A F 2024 Lithium and water: hydrosocial impacts across the life cycle of energy storage *WIREs Water* e1748