

# Quantifying the Impact of Water Needs for Lithium Production from Geothermal Brines in the Salton Sea KGRA

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## Keywords

*Water Use, Direct Lithium Extraction, Geothermal Energy, Renewable Energy, Salton Sea, Known Geothermal Resource Area*

## ABSTRACT

Geothermal brines from the Salton Sea Known Geothermal Resource Area (SS-KGRA) are highly saline and contain high concentrations of lithium. These brines are currently brought to the surface, used to produce geothermal energy, and then reinjected into the subsurface to maintain pressure in the geothermal reservoir. Before reinjection, there is an opportunity to extract the lithium. This is promising for securing a domestic supply chain of lithium to help meet energy storage needs for transition to a renewable energy grid. Previous analyses of how much water these processes will require in the region are limited by the lack of data available on freshwater use for both geothermal energy production and direct lithium extraction (DLE) processes. In this work, we develop improved estimates for water use in geothermal energy production and DLE processes. Our findings indicate that the water requirements for geothermal facilities may be higher than previously reported, potentially reaching 46.3 acre-feet per year per megawatt (AFY/MW) in some cases, compared to the average of 16 AFY/MW. For DLE, the ion exchange method is identified as potentially more water-intensive than liquid-liquid extraction. Additionally, the need to reallocate agricultural water to support these processes could strain local water resources and lower the water level of the Salton Sea.

## 1. Introduction

The surge in demand for energy storage devices has been fueled, in large part, by the rapid progress and widespread integration of renewable energy technologies in recent years. Lithium is highly valued as an optimal battery metal because it is the lightest, naturally occurring metal (Zeng et al. 2024). Lithium is primarily sourced from two types of deposits: hard rock, such as spodumene and lepidolite, and brine deposits. These sources contribute 34% and 66% of the global lithium supply, respectively. Extraction from brine is generally more cost-effective and energy-efficient compared to hard rock mining (Boroumand and Razmjou, 2024).

In the SS-KGRA, there are significant levels of lithium in the geothermal brine, and this brine is already being brought to the surface to produce energy. This provides a readily available source of lithium that can be extracted before the brine is reinjected into geothermal wells. As with any mineral extraction, the processes required consume other valuable resources such as freshwater. For the SS-KGRA, this is important because the region is already experiencing water shortages.

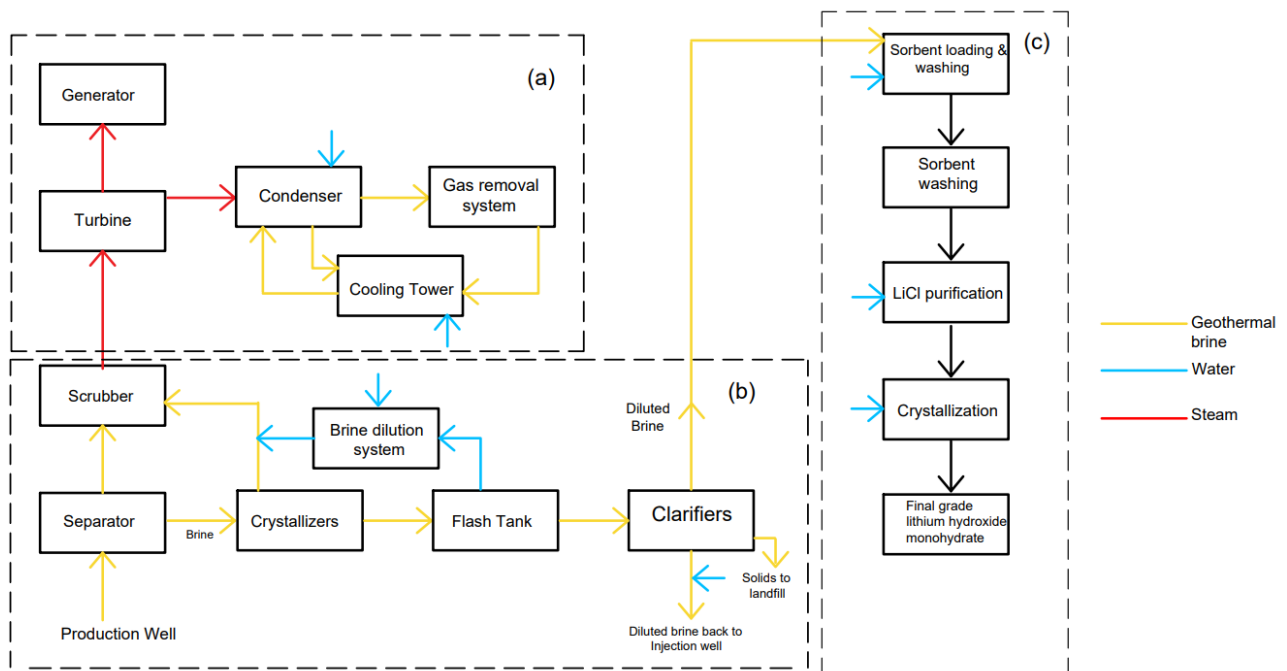
Previous studies have used public data to assess the environmental impacts of geothermal and lithium extraction in the region. These studies found that the growing geothermal/lithium industry would have a minor effect on regional water availability compared to the expected reductions in water allocation from the Imperial Irrigation District (IID). The expected IID reductions are a result of declining Colorado River levels (Busse et al. 2023; Dobson et al. 2023).

In this work, we improve the previous analysis with more up-to-date and detailed understanding of regional water use for geothermal and DLE processes. We collected data from the literature, industry, and patents to create water use ranges for regional geothermal energy production. We also synthesized data on potential DLE unit processes. This approach allowed us to scale potential water use to existing, planned, and maximum geothermal capacities.

## 2. Methods

### 2.1 Geothermal Production Overview

A geothermal power plant is typically comprised of a geothermal resource production facility, a power generation facility, and various ancillary installations. In Figure 1, these are indicated by the dashed boxes, and the ancillary installation shown in this instance is a DLE facility for producing lithium hydroxide monohydrate (Figure 1c). High-, standard-, and low-pressure steam is directed from the geothermal resource production facility (Figure 1b) to the power generation facility (Figure 1a) to operate the turbine generator system, producing electricity.



**Figure 1. General flow of freshwater (blue lines), geothermal brine (yellow lines), and steam (red lines) through the flash geothermal process in the SS-KGRA.**

The resource production facility (Figure 1a) comprises two types of wells: production wells and injection wells. During standard operations, the production fluids are channeled from production wells to the high-pressure separator. The high-pressure separator system divides the production fluid into steam and residual production fluid. The high-pressure steam is sent to the high-pressure scrubber and demister before it reaches the steam turbine. The remaining fluid moves through these same processes at standard-pressure and low-pressure to extract all possible steam for energy production (Figure 1b). The remaining fluid is processed to produce additional steam for energy production and prepare the remaining production fluid for reinjection (Black Rock Geothermal LLC 2023, Featherstone et al., 2020).

### ***2.1.1 Geothermal Freshwater Use***

Freshwater is mainly used for dilution and cooling throughout these processes. 29% of the total operating water, is introduced into the system as dilution water for geothermal brine moving from the crystallizer to the scrubber. This water flows through a condenser, mixing with fluid from the flash tank before joining the stream to the scrubber. Remaining production fluid from the flash tank is directed to clarifiers to remove solids before reinjection. This process has two stages: the first removes solids in slurry form, and the second dewateres the slurry. After passing through the secondary clarifier, spent geothermal fluid is directed to the injection wells, and freshwater is added before reinjection to prevent precipitation of solids.

Steam exiting the turbine is condensed in a shell-and-tube condenser, where freshwater is added to support the cooling process. The resulting condensate is piped to the biological oxidizer for hydrogen sulfide removal. The non-condensable gas (NCG) removal system uses ejectors and vacuum pumps to extract gases from the condenser and directs them to the cooling tower basin. Water circulates through the cooling tower, cooled by evaporation and air heat exchange, and is then pumped back to the condenser to condense the steam. This circulating water, which constitutes 70% of the plant's operating water, is managed by vertical wet-pit pumps for both turbine condensers and plant auxiliary cooling needs.

To quantify the amount of water required for geothermal energy production, we extracted information from Environmental Impact Reports (EIRs) that have been submitted by companies in the SS-KGRA. Water use data for construction and operation of geothermal facilities was provided in documentation from Controlled Thermal Resources, Energy Source Minerals, and Berkshire Hathaway (BHER) (Energy Source, 2012; Black Rock Geothermal LLC, 2023; Elmore North Geothermal LLC, 2023; Morton Bay Geothermal LLC, 2023; Controlled Thermal Resources, Inc., 2024).

### ***2.2 Lithium Extraction Process***

The conventional method for extracting lithium from brine involves pumping the lithium-rich brine into expansive surface ponds that can cover thousands of acres. In these ponds, lithium and other salts are concentrated through passive solar evaporation over the course of a year or more to increase the lithium concentration to about 6,000 mg/kg (Khalil et al., 2022).

DLE is emerging as a more efficient, alternative to this approach. DLE approaches offer distinct advantages over conventional evaporation ponds and Hard rock mining methods, such as reduced land and overall water usage (fossil and freshwater), faster time-to-market for lithium products,

and lower carbon emissions during operations (Warren, 2021). In broad terms, DLE techniques can be categorized into three main classes: adsorption, ion exchange, and solvent extraction. Regardless of the specific DLE technique employed, either alone or in combination with additional processing steps, these methods must be capable of selectively extracting lithium from chemically complex brines containing high concentrations of various ionic species like sodium, potassium, calcium, magnesium, borates, sulfates. Moreover, for geothermal brines, silica as well as potentially elevated levels of iron, manganese, and other dissolved components, must be considered (Warren, 2021). To quantify freshwater use for various lithium extraction processes, we conducted a literature search and evaluated industry and patent data.

### ***2.3 Local Water Cuts Proposed***

In December 2023, the Imperial Irrigation District (IID) (local water authority in the Imperial Valley) with other local water authorities, signed an agreement for water conservation into 2026. The water districts, in return, receive funding from the Inflation Reduction Act to support water conservation efforts. IID plans to focus on agriculture and fund an irrigation efficiency program (Saegert, 2023). In 2023, IID agreed to conserve 100,000 AF. IID is expected to conserve 800,000 AF between 2024 – 2026 (U.S. Department of the Interior, 2023). These additional cuts will be in exchange for \$175 million in federal funds for projects at the Salton Sea (IID, 2024b). Conservation measures are to be determined by IID (Garcia, 2024). In previous analysis, we considered at 10% and 40% cut to water allocation for the region (Busse et al., 2023; Dobson et al., 2023). The proposed 800,000 AF over 3 years (Garcia, 2024), if divided equally between each year, represents a 8.6% cut to the 3.1 million AF annual entitlement (IID, 2024a), which is what we will consider herein.

## **3. Results and Discussion**

### ***3.1 Geothermal Water Use in the SS-KGRA***

In the United States, there are more than 90 operational geothermal power plants, many of which have been running for over three decades (Robins et al., 2021). The common types of geothermal plants include dry-steam, flash-steam, and binary cycle, with flash-steam plants being the most prevalent in the SS-KGRA. According to historical and estimated water use data, geothermal facilities in the SS-KGRA typically require an average of 16 acre-feet (AF) of water per megawatt (MW) of net generation capacity annually (Dobson et al., 2023). However, water needs can vary significantly across different facilities, ranging from as low as 0.4 AF to as high as 32 AF per MW each year (Dobson et al., 2023).

Here we provide a breakdown of the water use for geothermal facilities in the SS-KGRA that have reported water use for construction (Table 1) and operation (Table 2). Freshwater in this analysis is water purchased from IID. Freshwater required for construction is minimal compared to the freshwater required for operation over the lifespan of the facilities. Operational freshwater use from these facilities ranges from 4 – 46 AFY/MW (Table 2), higher than what was previously reported. It is important to note that the total required water for operation is higher than the freshwater requirement. For example, Elmore North and Morton Bay require twice as much water, but the plant to use steam condensate for the additional water (Elmore North Geothermal LLC

2023; Morton Bay Geothermal LLC 2023). Black Rock Geothermal plans to use 80% steam condensate to meet their total required water need (Black Rock Geothermal LLC 2023).

**Table 1. Summary of the construction freshwater use for proposed geothermal facilities in the SS-KGRA.**

Geothermal Unit	Phase of Water Use	Source	Quantity of water used (Reported Units)	Duration (months)	Total Freshwater Use (AF)	Net Energy Output (MW)	Citations
Hudson Ranch (HR-2)*	Well Drilling	IID	73.7 AF	2	128.7	49.9	Energy Source, 2012
	Facility Construction	IID	55 AF	28			
Hell's Kitchen PowerCo 1	Dust Control	IID	50,000 gallons/day	10	87	49.9	Imperial County Planning & Development Services Department (2022); Controlled Thermal Resources, Inc. (2024)
Black Rock Geothermal	Dust suppression, concrete prep, hydrostatic testing of pipelines, potable	IID	150 AFY	29	363	77	Black Rock Geothermal LLC, 2023
Morton Bay	Dust suppression, concrete prep, hydrostatic testing of pipelines, potable	IID	150 AFY	29	363	140	Morton Bay Geothermal LLC, 2023
Elmore North	Dust suppression, concrete prep, hydrostatic testing of pipelines, potable	IID	150 AFY	29	363	140	Elmore North Geothermal LLC, 2023

\* Facility was never constructed.

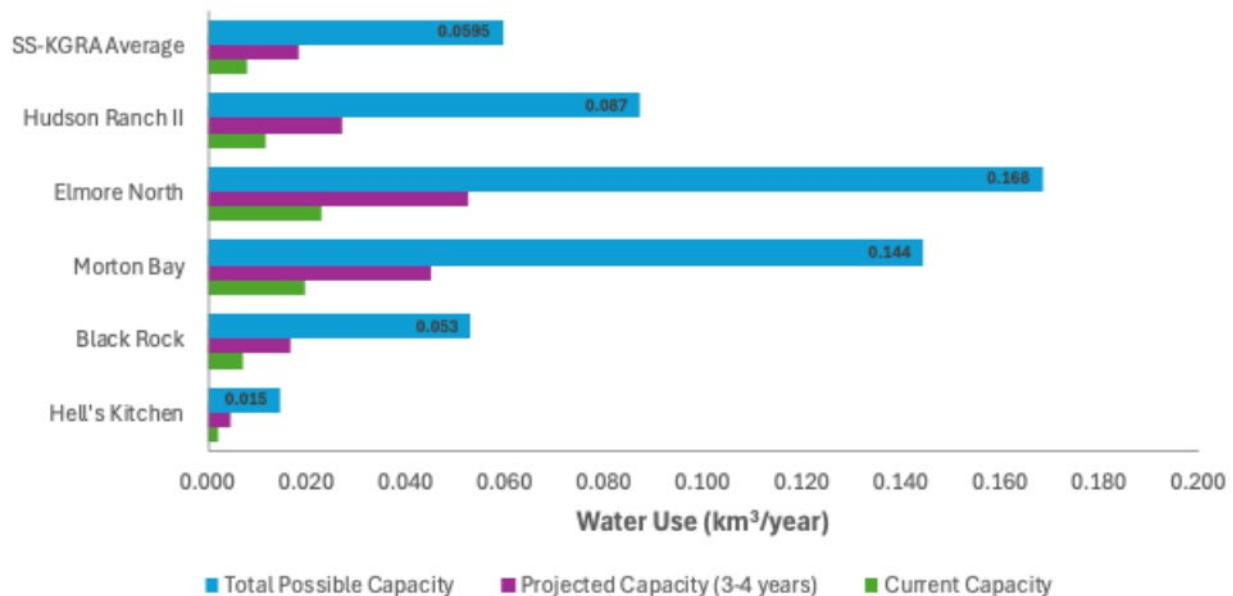
**Table 2. Summary of the operational water use for proposed geothermal facilities in the SS-KGRA.**

<b>Plant Name</b>	<b>Phase of Water Use</b>	<b>Source of Water</b>	<b>Quantity of Water (AFY)</b>	<b>Total Freshwater (AFY)</b>	<b>Net Energy Output (MW)</b>	<b>Water Use (AFY/MW)</b>	<b>Citations</b>
Hudson Ranch (HR-2)*	Cooling	Steam Condensate	2,740	1200	49.9	24.0	Energy Source, 2012
		IID	44				
	Brine Dilution	1,124					
	Freshwater Pond Evaporation	20					
	Miscellaneous	12					
Hell's Kitchen PowerCo 1	Cooling tower makeup, other uses	IID	200	200	49.9	4.01	Imperial County Planning & Development Services Department (2022); Controlled Thermal Resources, Inc. (2024)
Black Rock Geothermal	Well Maintenance	IID	6.95	1132	77	14.61	Black Rock Geothermal, LLC (2024)
	RO, plant wash down, cooling tower makeup	IID	1125				
		Steam Condensate	4500				
Morton Bay	Plant water, dilution water, plant wash down, cooling tower makeup	IID	5560	5560	140	39.71	Morton Bay Geothermal LLC, 2023
		Steam Condensate	5560				
Elmore North	Plant water, dilution water, plant wash down, cooling tower makeup	IID	6480	6480	140	46.29	Elmore North Geothermal LLC, 2023
		Steam Condensate	6480				

\* Facility was never constructed.

The average geothermal water use from the analysis in Dobson et al. (2023) was used as a comparison to the water use scenarios identified in Table 2. Figure 2 illustrates this impact across the geothermal production scenarios in the region. The current capacity is 400 MWe, the projected capacity of facilities proposed across the next 3 – 4 years is an additional 520 MWe, and the total possible capacity of the resource is 2950 MWe (Kaspereit et al. 2016).

The maximum water use was identified for Elmore North at 46.3 AFY/MW (57110 m<sup>3</sup>/MW) compared to the 16 AFY/MW (19735 m<sup>3</sup>/MW) average. If all facilities operated at this water use rate, it would almost triple the impact of geothermal in the region, representing a non-negligible increase in regional water use for geothermal energy production.



**Figure 2. Comparison of how different facility water use projections for geothermal production would compare to the SS-KGRA average water use projections from Dobson et al. (2023).**

### 3.2 Lithium Extraction Water Use

As mentioned previously, the main DLE processes can be categorized as adsorption, ion exchange, and solvent extraction processes. In the SS-KGRA the expected processes are adsorption and ion exchange. Unfortunately, most literature studies we identified did not quantify water use of these processes. Moreover, many did not test their proposed method with brines similar to those in the Salton Sea. Table 3 provides a summary of some of the brines studied at bench-scale for DLE in comparison to the brine composition in the SS-KGRA. Studies that evaluated synthetic brines often did not include fluid composition in this form. For example, Zhang et al. (2024) reported NaCl, LiCl, MgCl<sub>2</sub>, and CaCl<sub>2</sub> concentrations of their synthetic brine. The geothermal brine from Suharyanto et al. (2024) is the most similar we have found to the Salton Sea brines, and this study evaluated an adsorption process, but did not report water use.

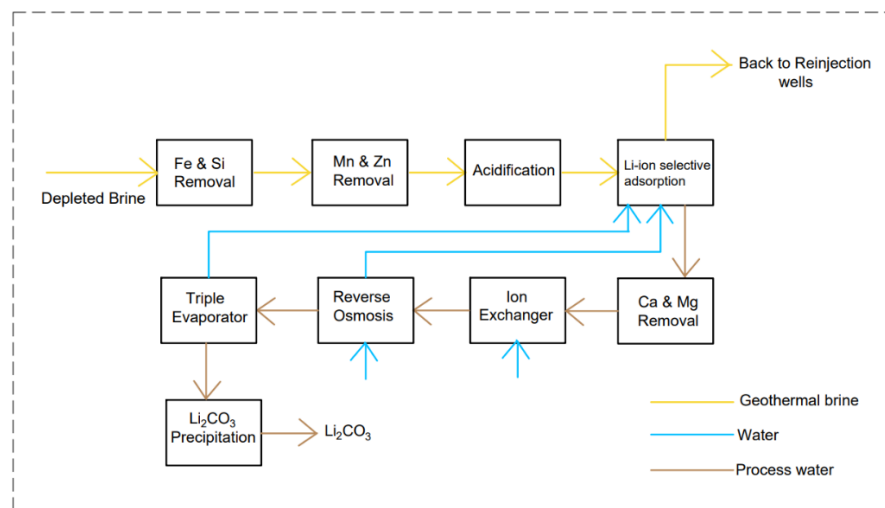
**Table 3. Summary of geothermal brine composition in the SS-KGRA compared to brine compositions from DLE studies in the literature.**

Type of Fluid	Dissolved Solids (mg/L)					Citation
	Lithium (Li)	Sodium (Na)	Magnesium (Mg)	Calcium (Ca <sup>2+</sup> )	Boron (B)	
Salton Sea Brine	211	52,000	160	24,000	350	(Gagne et al. 2015)
East Mesa Brine	6.3	2,600	3.4	130	5.4	(Gagne et al. 2015)
Salt Lake Brine	969	77,650	34,010	176	807	(Luo et al. 2021)
Geothermal Brine	27.02	8,834	422.66	1308.3	86.48	(Suharyanto et al. 2024)

Based on these constraints from the bench-scale literature, we have summarized the water use information we were able to obtain for DLE processes from patents and industry EIRs.

### 3.2.1 Ion-Exchange

Based on a 2020 patent from EnergySource Minerals LLC, we developed a flow diagram of the proposed process that would exist in an ion-exchange-based DLE facility (Figure 2). This flow includes freshwater flows into the system (blue lines), geothermal brine flow (yellow lines), and process water (brown lines) (Featherstone et al., 2020). For this process, EnergySource Minerals LLC reported the anticipated water use for the entire process at 3400 AFY, but specific allocation of this water was not specified. During normal operation, they also identify a water requirement for fugitive dust control at 56 AFY, which sums up to an operational water need of 3456 AFY at the DLE facility. The estimated duration of the project is 30 years, consuming approximately 102,112 AFY water in its entire duration to produce 17,000 tonne of lithium carbonate equivalent (LCE) (Energy Source, 2012). Though, as mentioned in Dobson et al. (2023), EnergySource has indicated that this may be an overestimate of water use.



**Figure 3. General flow of freshwater (blue lines), geothermal brine (yellow lines), and process water (brown lines) through the ion exchange process as it is often set up in the SS-KGRA (Featherstone et al., 2020).**

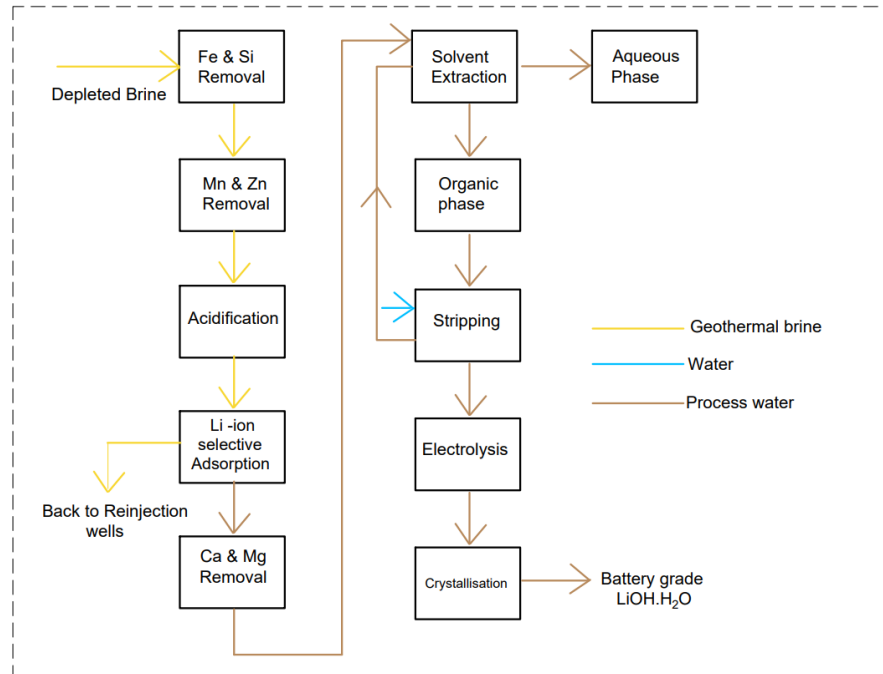
In their proposed process depleted brine is mixed with limestone to precipitate out iron (Fe) and silicon (Si) compounds, and quicklime is used to remove manganese (Mn) and zinc (Zn) under conditions that do not remove lithium. The addition of these compounds raises the pH of the brine, which is then lowered through the addition of hydrochloric acid (HCl). An aluminum monohydroxide (AlOH)-based cationic resin is used to selectively adsorb lithium ions from the pretreated brine solution. The adsorbed lithium is then stripped from the resin using freshwater, yielding a lithium-enriched solution for further processing. The remaining geothermal fluid is diverted back to the reinjection well (Featherstone et al., 2020).

In the lithium-enriched solution, residual calcium (Ca) and magnesium (Mg) are precipitated out by adding sodium hydroxide and soda ash. An ion exchange step further removes any lingering divalent ion impurities like Ca, Mg and boron (B). To increase the lithium concentration, the solution volume is reduced through reverse osmosis followed by triple-effect evaporation. The triple effect evaporator utilizes steam from geothermal operations and/or a fuel boiler to operate. After processing through the evaporator, the lithium concentration in the product stream is increased from about 5,000 ppm to about 30,000 ppm. Soda ash is introduced to precipitate lithium as lithium carbonate technical grade product.

The precipitated battery-grade lithium carbonate goes through final steps of washing to remove residual impurities, followed by centrifugation to dewater the solid product. The washing fluid is not identified. Finally, the dewatered lithium carbonate is sent to a rotary dryer for complete drying, yielding the final battery-grade lithium carbonate product (Featherstone et al., 2020). A recent study by Schenker et al. (2024) conducted a parameterized life cycle assessment (due to lack of available data) of lithium carbonate production from geothermal brines in the SS-KGRA and Upper Rhine Graben in Germany. They identified that large amounts of freshwater are used in the adsorption process and for regenerating the ion-exchange media. This is in line with where we have identified freshwater inputs in the Featherstone et al. (2020) process.

### 3.2.2 Liquid-Liquid Extraction

In the liquid-liquid extraction process, impurities are removed from the geothermal brine before lithium is extracted using an adsorption process to selectively bind lithium ions to a solvent. Two streams result from the adsorption process: one returns to the reinjection well, while the purified liquid containing LiCl undergoes further purification. The pH of the lithium chloride stream drops from 5 to about 2.5 before entering solvent extraction process, which occurs in tall, pulsed columns. Here, extraction separates impurity ions in the aqueous phase from lithium ions in the organic phase. Sulfuric acid is used to strip the lithium from the organic phase back into an aqueous solution. The organic phase is then able to be reused. The final purification step involves electrolysis and crystallization to produce dried lithium hydroxide crystals.



**Figure 4.** General flow of freshwater (blue lines), geothermal brine (yellow lines), and process water (brown lines) through the liquid-liquid extraction process for DLE (Featherstone et al., 2020; Sun et al., 2021).

We attempted to extract data for freshwater use in liquid-liquid extraction processes from the literature, but we did not find quantitative values for water use. We were able to extract some information on where water is used in the process. This analysis indicated that liquid-liquid extraction may reduce freshwater consumption compared to ion exchange, as it eliminates the need for resin desorption and regeneration, which are major freshwater consumers. Only the stripping step in this DLE process consumes freshwater, as indicated in Figure 4.

### 3.3 Impact on Regional Water Resources

Due to the lack of quantified water use from applicable DLE processes in the literature, water use for lithium extraction in this analysis remains the same as what was estimated in the Dobson et al. (2023) report. This value is the average estimated water use from three companies – EnergySource Minerals, Berkshire Hathaway, and Controlled Thermal Resources – at 328 m<sup>3</sup>/tonne of lithium carbonate equivalent (Paz et al., 2022; Controlled Thermal Resources, Inc., 2024). Based on the agreed upon cuts to water resources in the SS-KGRA (8.6% of the 2022 allocation), we evaluated the possible impacts of geothermal expansion under average and high water use conditions and a scenario of average water use for lithium extraction on the regional water supply (Figure 5).

If the full geothermal field was utilized, the high geothermal water use estimate would require 1.4 times the water allocation for renewable energy compared to the average water estimate. For the planned geothermal expansion, the higher geothermal water estimate would only increase 1.2 times. For context, this additional water equates to a reduction in 2025 acres of land irrigation in the region.

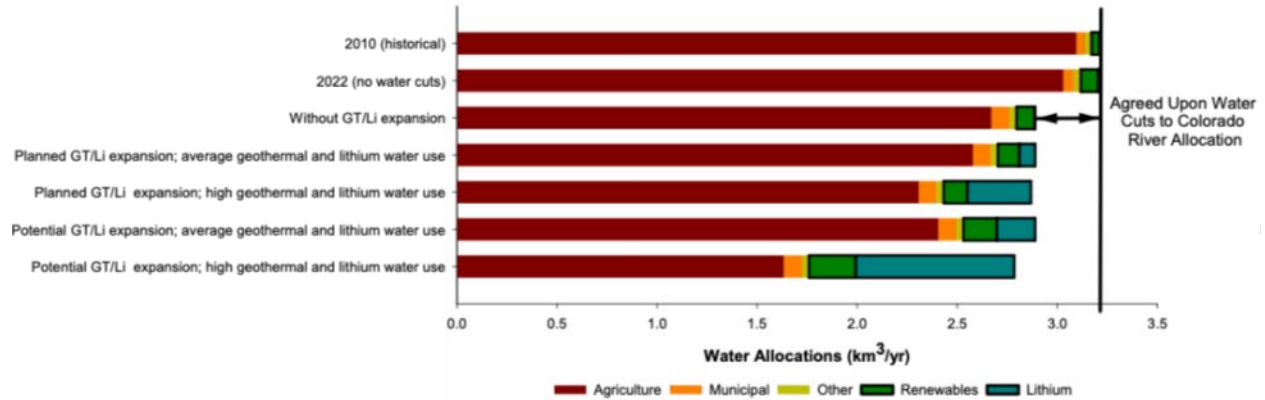


Figure 5. Summary of expected impact of water cuts, geothermal expansion, and DLE on local water availability.

#### 4. Conclusion

This study provides a preliminary analysis of the unit process water requirements for both geothermal energy production and direct lithium extraction (DLE) processes at the SS-KGRA. By developing more detailed water use information, we were able to quantify potential water use scenarios and their impact on the region. Our results show that geothermal facilities in the SS-KGRA may require as much as 46.3 AFY/MW, even though the average reported use in the region is 16 AFY/MW. For DLE processes, we expect the ion exchange method to be more water-intensive than liquid-liquid extraction, with the latter eliminating water needs for resin desorption and regeneration. But from the patents submitted by companies in the region, ion-exchange is likely the process that will be used. Further, we evaluated the potential impacts of the agree upon water cuts (8.6%) along with scenarios for geothermal and lithium production expansion in the region. This analysis indicates that maximizing geothermal and DLE capacity could strain local water resources.

Reducing the available agricultural water in the region by reallocating it to geothermal energy expansion and lithium production has the potential to impact the water level of the Salton Sea, and thus the toxins released to the air because of this decline. This will be exacerbated by current regional efforts to improve irrigation efficiency, which will reduce runoff to the sea. This impact was outside the scope of this work, but it should be evaluated further.

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