

The Green Energy Paradox: The Environmental Impact of Lithium on Groundwater

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Abstract

As the world transitions away from fossil fuels towards more renewable energy sources, the demand for lithium has increased dramatically in recent years. Lithium is a critical component to power electric and hybrid vehicles, and for the production of batteries for energy storage, computers, phones, and other electronics. In the United States, Nevada maintains dominance in lithium brine deposits, lithium processing, battery manufacturing, and recycling due to the geological landscape of the region. According to the International Energy Agency (IEA), in 2022 there was a 180% increase in lithium production since 2017. However, the lithium mining extraction process has raised concerns related to water resources. Lithium extraction methods require large amounts of water, pumped from underneath the surface and brought to the surface before being gathered by evaporative extraction.

In my research, I am examining how lithium development processes affect the availability of groundwater resources by comparing the water storage and pumping rates at the Silver Peak lithium mine compared to a nearby basin, using OpenET data. Although the methodology was preliminary, it provides valuable insights in the pumping patterns of Silver Peak and the feasibility of the development of a water budget. The calculated measurements of pumping were greater than what was reported in the SEC technical report, indicating that the reported rates may underestimate the actual groundwater extraction rates at Silver Peak. These results show a novel approach in estimating the hydrological impacts of lithium mining without referring entirely on reported values, which can be limited or unavailable. Due to the constant concern of water availability in the western United States for human consumption and agriculture, lithium production does not escape scrutiny, as it further impacts already limited

water resources. An increased understanding of the environmental, economic, and social impacts of lithium mining can better guide us in our involvement in the global energy transition.

Introduction

Lithium is an alkali metal, silver-white in color, with a very high energy density, and lightweight. Due to its properties, it has been proved to be the ideal candidate for major contributions in CO₂ emission reductions in transportation and the power grid. Its high energy density and low weight make it suitable for smaller and more efficient battery constructions such as lithium-air and lithium-sulfur (Flexer, 2018). The development of a broader operating temperature range and a higher voltage per cell compared to other battery types also contributes to the increased emergence of efficient battery technology (Ogilvie, 2023). With the widespread success in electric vehicles (EVs) and the increase in renewable energy generation, such as solar and wind, 87% of the current lithium demand is dominated by the energy sector (U.S Geological Survey). Battery manufacturing is expected to increase to meet the determined climate targets and compliance in climate policies from around \$85 billion in 2022 to \$400 billion in 2030 (Jowitt, 2024). In addition to these newer lithium uses and developments, lithium is also historically used in ceramic and glass production, pharmaceuticals, and in lubricating greases (Jowitt, 2024). Consequently, lithium is a critical element in the energy sector, industrial processes, and medical developments.

In the United States, specifically Clayton Valley in Nevada, lithium is found in salar or continental brine deposits, extremely salty groundwater containing a variety of metals in solution in closed sedimentary basins. When surface water and groundwater flow in, the water does not reach the Atlantic or Pacific Ocean. Instead, water can only leave by evaporation, leading to the accumulation and cycle of highly concentrated lithium. Groundwater that is enhanced with

brines often contain lithium broken down from the surrounding region, which are capable of having large lithium concentrations. Consequently, areas with these closed hydrologic basins are ideal for lithium extraction and production. The area in and around Silver Peak has always been an ideal area for mineral extraction. In the 1860s, the town was developed around silver and gold mines, and since the mid-1960s, its main focus has been the extraction of lithium (Voiland, 2023). The lithium mine in Nevada, Silver Peak, operated by Albemarle Corporation since 1966 produces 5,000 metric tons of lithium carbonate equivalent (LCE) annually and is projected to double in 2025 due to expansion developments (Romsaas, 2023). This region is unique as it has the only operating lithium mine in the United States and also contains the lithium processing, battery manufacturing processes, recycling, and research facilities (Jowitt et al., 2024).

Matthew Weingarten's project contains two phases to investigate the hydrological impacts of lithium mining. The first phase focuses on developing casual evidence from publicly available data on a global scale about the effects of lithium mining and production on water quantity and quality. The second phase focuses specifically on the American West to investigate the current and future scale of lithium production in this region through a hydrological model of lithium activity. This topic is particularly intriguing as there is a lack in existing research on the correlation between lithium mining and surface and groundwater depletion. Other research has focused on the manufacturing of lithium-ion batteries, but little research has been done on the extraction and mining methods of lithium. In order to understand the environmental impacts of these processes, I have developed an integrated research question: Can we quantify the impact of lithium mining on groundwater using geo-physical data? The results obtained from this study can act as a starting point in informing policy makers on the clean energy transition, in order to reach climate targets and comply with national and international policy standards.

Literature Review

Environmental degradation through mining for energy sources: the case of the shrinking Laguna

Santa Rosa Wetland in the Atacama Region of Chile

Published by Energy Geoscience, this study investigates the linkage between lithium mining and the degradation of a surrounding wetland that is groundwater-dependent. Chile is one of the largest global producers of lithium and the production is predicted to increase even more with the recent commencement of lithium mining at Salar de Maricunga. The study focuses on the threat of the Laguna Santa Rosa's wetland that provides suitable habitat for a vast number of species. Through the application of remote sensing technologies for image collection with satellite imagery, specifically a Landsat-5 Thematic Mapper, a "decreasing trend in the water surface area at LSR, a hypersaline lake at the southern extreme of Salar de Maricunga, a salt flat in the Atacama Region of Chile" was identified through the years 1993 to 2014 (Alam, 2022). This decreasing trend reveals the shrinking of this crucial wetland due to significant anthropogenic intervention.

When studying the water inside Laguna Santa Rosa, the input of water is through natural processes while the output of water is much more intense and dramatic due to the water extraction and pumping for lithium collection. This study is relevant to my research because it provides visual evidence and monitoring of a given area over a period of time of how the increase in lithium mining near groundwater-dependent ecosystems contributes to the depletion of valuable water resources. Understanding the effects on a global scale is valuable in order to understand the effects and distribution at a more local scale in the United States.

Lithium recovery from brines: A vital raw material for green energies with a potential environmental impact in its mining and processing

Published by the Science of the Total Environment, this study reviews the current technology and new proposed technology in lithium recovery as well as investigates the overall sustainability of the lithium extraction process, with an emphasis in water usage in the Puna de Atacama plateau of northern Chile. The concern that arises with lithium extraction processes does not necessarily revolve around the highly saline brine water, but instead revolves around the use of freshwater in different steps of the extraction and purification process. Freshwater is used in the construction of the concentrated lime solution as well as in the regeneration of lithium carbonate which involves the washing, re-dissolving and reprecipitating of the primary lithium carbonate (Flexer et al., 2018). Additionally, the interactions between the aquifers (brine and freshwater) poses some significant environmental concerns. With the huge lack of reported measurements of the hydrodynamic behavior between the aquifers as well as the lack of measurements of fresh water balances surrounding the salars, it is difficult to justify and quantify the impact mining corporations are having on groundwater resources. However, it is understood that the interconnection of these aquifers will be mostly contingent on the pumping rate and the location of pumping wells (Flexer et al., 2018, p. 1194). It is also known that “even in the absence of mining exploitations, these arid areas show a negative water balance” (Flexer et al., 2018, p. 1195) meaning that the amount of water that is discharged out of the basin is larger than the influx of recharge waters and precipitation.

The incomplete quantifiable measurements of water storages leads to misconceptions on the impact that lithium mining has on water resources as well as what embodies sustainable water use. My research aims to progress this lack of research. This study advances what is known to further understand and show the hydrodynamic behavior between different aquifers as well as show the negative water balance of the Silver Peak Basin compared to an adjacent basin

using evaporation and precipitation data. Through evaporation and precipitation data, we can measure the water storage in each basin and identify variations in storage levels, which suggests the extent of pumping occurring at Silver Peak.

Lithium in Nevada - origins, extent, role in the energy transition, and implications for economic development and national security

Published by Nevada Bureau of Mines and Geology Special Publication, this study introduces lithium and its composition, geological properties, how it is formed and concentrations in groundwater, lithium reserves in Nevada, and the role of lithium in the current transition to a more renewable economy. Nevada has a suitable climate and geographical characteristics for the formation of lithium. The arid climate, existence of closed basins, the spreading and sinking of the earth's crust, volcanic and geothermal activity, and mature groundwater to produce a brine are all characteristics that allow for the accumulation of lithium in groundwater (Jowitt, p.21). Even though much of the state is known for containing lithium due to the abundance of closed basins, not all closed basins contain lithium. For example, Pyramid and Walker Lake have great potential in the formation of lithium due to their closed hydrologic basins, but lack significant deposits due to the lack of rhyolite ash in their drainage areas. On the other hand, Clayton Valley is ideal for lithium formation due not only the existence of a closed hydrologic basin, but also the tectonic activity and movement of the crust that results in layers of volcanic rock and ash, sediments, and evaporite materials (Jowitt, p.31). The valley is also surrounded by other higher elevated basins, suggesting that areas such as Tonopah could have groundwater flowing through the subsurface into Clayton Valley, leading to a bigger drainage area that extends beyond the boundaries of the valley.

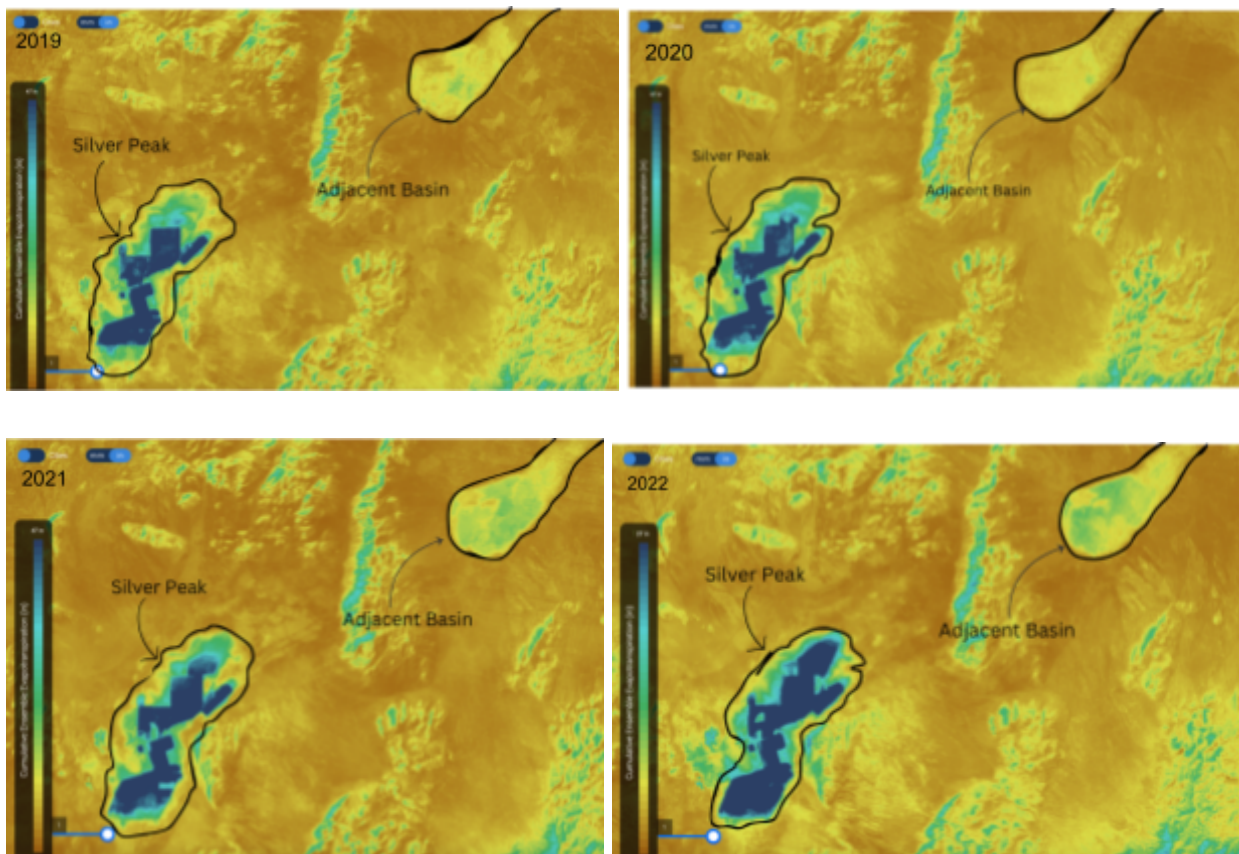
The Silver Peak mine, located in Clayton valley is the largest operating mine in the United States due its suitable geographical, geological, and hydraulic conditions. The method for extraction used here is known as “evaporative concentration”, where brines from the groundwater aquifers are pumped into shallow artificial ponds to allow for a lengthy open-air evaporation process. Brine is pumped from six different aquifers through multiple wells and spread throughout nine different ponds for evaporation and concentration of lithium. The on-site chemical plant then precipitates lithium carbonate and lithium hydroxide to produce around 5,000 metric tons of lithium carbonate from about 3.8 billion gallons of brine annually (Jowitt, p.33). Although this is seen to be one of the most efficient methods for lithium recovery, issues revolving around sustainable water use, time frame of about 18 to 24 months, contamination of groundwater through leakage of waste material, scaling up difficulty, and land use issues can make the process difficult (Jowitt, p.33). This source plays a huge role in understanding the intersections between the landscape, hydrology and mineral composition and how these factors influence extraction methods such as their feasibility, success, and efficiency.

Thesis Statement

The rapid increase in lithium mining and production, directed to meet the demand of electric vehicle production and renewable energy technologies, poses various environmental concerns and challenges related to surface and groundwater resources. This research aims to provide a framework in how this low-carbon alternative is likely to create disputes between water availability and the transition away from fossil fuels. My scope of the study is obtaining publicly available evaporation and precipitation data of the Silver Peak lithium mine compared to an adjacent basin from 2019-2023 to understand the pumping patterns at Silver Peak.

Methods

Data was collected through OpenET, a publicly accessible tool that provides granular and reliable evapotranspiration and precipitation data across the United States through high resolution satellite-based remote sensing data. Data is provided on vast timescales: daily, monthly, and an annual basis. Using the Data Explorer and creating polygons of the Silver Peak mine and the chosen adjacent basin, evapotranspiration and precipitation datasets for each region of the Silver Peak mine and for a nearby basin were collected. However, OpenET has a maximum area of the data that can be collected for a given area, which is around 2500 acres. Therefore, data was collected for each part of the mine, totaling a given area of 10,902.73 acres for Silver Peak and 5,276.166 acres for the adjacent basin from 2019-2022.



The landscape showing the Silver Peak mine and the chosen adjacent basin is shown above.

These photos were obtained from OpenET in the raster view to visualize the changes in

evapotranspiration from 2019-2022. The rates of evapotranspiration are much higher at Silver Peak due to the high amounts of water that is pumped to the surface in wide pools to be evaporated. Using a basic water storage equation: $\Delta S = P - ET$ where ΔS is change in water storage, P is precipitation, and ET is evapotranspiration, water storage is estimated for Silver Peak and the chosen adjacent basin. For each part of the Silver Peak as well as each part of the adjacent basin, the calculated water storage was added together in order to obtain a single value for the change in water storage. Water Storage was estimated with the average, as well as the low and high ranges of evapotranspiration. These values are communicated through mid ET, low-end ET, and high-end ET. The difference in water storage between the two basins suggests the pumping patterns at the Silver Peak mine. Since the chosen adjacent basin is smaller than Silver Peak, the adjacent basin was scaled by 1.4 to attempt a direct and proportional comparison of the basins. By comparing the estimated water storage changes between the two basins, we can quantify the impact of groundwater extraction in Silver Peak and identify any anomalies related to pumping activities.

Additionally, a comparison will be made between the differences in water storage between the two basins and the wellfield pumping rate of Silver Peak. The wellfield pumping rate was found from a SEC technical report/pre-feasibility study of the Silver Peak Lithium operation done by srk consulting for the Albemarle Corporation.

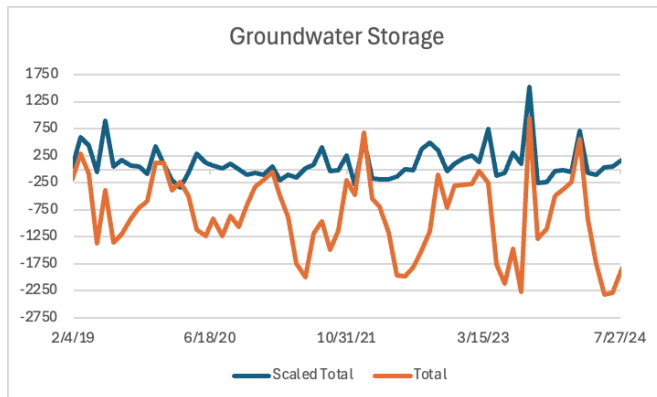
Analysis and Results

The water storage differences (ie. pumping rates) were calculated between three different variables. Both basins low-end storage, the Silver Peak low-end storage against the adjacent basin mid-end storage, and both basins mid-end storage are the variables that were compared between the Silver Peak basin and the chosen adjacent basin, as well as the pumping rates from

the SEC technical report/pre-feasibility study from 2019-2023. These comparisons, along with the pumping rates from the SEC technical report/pre-feasibility study are displayed in a table to illustrate the findings.

Row Labels	Sum of Low ET (SP) - Mid ET (AB)	Sum of Low ET (SP) - Low ET (AB)	Sum of Mid (SP) - Mid (AB)	Sum of SP Pumping
2019	-5,602.66	-8,992.11	-17,464.80	13,368.00
2020	-5,455.24	-8,306.69	-19,134.67	12,904.00
2021	-6,229.83	-10,730.93	-17,478.13	11,291.00
2022	-7,921.70	-12,405.54	-20,268.37	12,904.00
Grand Total	-25,209.44	-40,435.27	-74,345.98	50,467.00

The following charts were created to show the temporal and seasonality of the groundwater storage between the period of 2019-2023. Comparing the Silver Peak low-end storage with the adjacent basin low-end storage, a water storage difference of -8992.108 AF in 2019, -8306.6894 AF in 2020, -10730.6894 AF in 2021, and -12405.541 AF in 2022 were

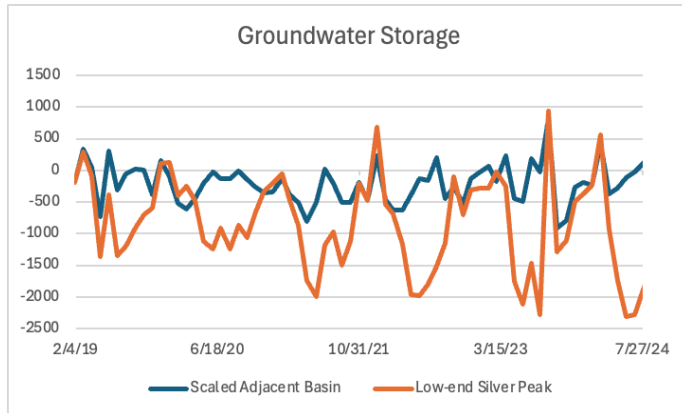


calculated, totaling -40,435.27 AF. The pumping rates of Silver Peak from the SEC technical report/pre-feasibility study are regarded as Sum of SP Pumping in the table above. Due to the small differences within the pumping rates, this suggests that

the low-end pumping rate of Silver Peak is most aligned with the actual pumping rate from the SEC technical report/pre-feasibility study. It can be implied that the reported pumping rates are more consistent with the low-end storage range, leading to a potential underestimation of pumping rates at the Silver Peak lithium mine.

Comparing the Silver Peak low-end storage to the adjacent basin mid-end storage, a water storage difference of -5602.6562 AF in 2019, -5455.2422 AF in 2020, -6229.8336 AF in 2021, and -7921.7046 AF in 2022. A smaller water storage difference is evident here as we are

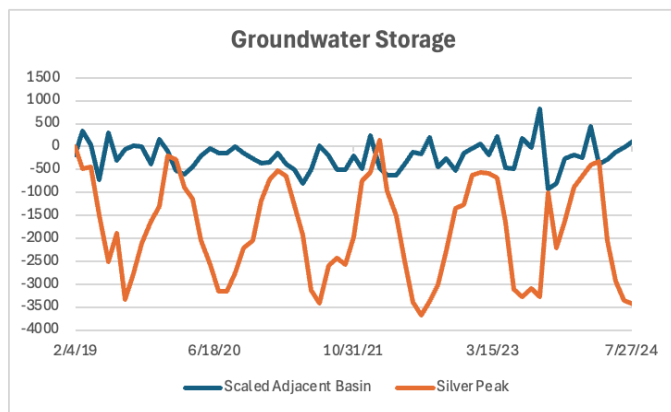
comparing the low-end storage against the mid-end storage. Even though the difference is smaller, the low-end range of Silver Peak having a bigger pumping rate than the mid-end of the adjacent basin suggests that the amount of pumping at Silver Peak is substantial enough to



surpass natural water storage differences, which can strengthen the possibility that reported pumping rates may underestimate the actual pumping occurring in the Clayton Valley. This difference in water storage is indicated in a chart to visualize the findings, revealing that the water loss

in Silver Peak is much more severe than the water loss in the adjacent basin. In the more recent years, 2022 and 2023, we see increasing differences in water storage than in 2019 and 2020, suggesting the effects of pumping rates and/or climatic changes on groundwater availability, and contributing to the worsening water exacerbation in the arid basin.

Lastly, comparing the mid-end storage of Silver Peak and the adjacent basin, a water storage difference of -17464.801 AF in 2019, -19134.672 AF in 2020, -17478.135 AF in 2021,



and -20268.374 AF in 2022 were calculated. Comparing these values to the pumping rates released by the SEC technical report/pre-feasibility study, there is a consistent trend that shows the calculated pumping rate to be greater than the pumping rates released. In 2019, a

pumping rate of -17464.801 AF compared to 13368 AF suggests that the actual pumping rate at Silver Peak may have been higher than what was reported, indicating a potential underestimation of water extraction in the SEC technical report/pre-feasibility study. This is a consistent observation throughout the 2019-2022 time frame.

According to the chart above, comparing mid-level Silver Peak and the mid-level adjacent basin, we are able to see the large seasonal variation in groundwater storage. There is a consistent trend of a staggering low groundwater storage every year between summer months while in the adjacent basin, water balance is stable with little variation. In 2019, the peak low was -3341.869 AF in July. In 2020, the peak low was -3158.47 in June. In 2021, the peak low was -3424.361 AF in June. In 2022, the peak low was -3683.966 AF in June, and in 2023, the peak low was -3283.849 AF in August. We see the same trends with the low-end storage of the basins as well as the mid-end adjacent basin compared to the low-end of Silver Peak. This could be mainly due to the seasonal differences in the landscape, as well as high demand, or competition of water resources with the surrounding agriculture growing season. This arid region already experiences a low groundwater storage in the summer due to higher evaporation rates and lower precipitation rates in the summer. With minimal rainfall, the natural recharge of the basin is reduced so when groundwater pumping for lithium extraction is added to the mix, groundwater levels are particularly low and pumping impacts are more pronounced. Additionally, pumping rates might increase in the summer to meet the demand, creating bigger disparities between the Silver Peak and adjacent basin groundwater levels. Lastly, it could be possible that Silver Peak and the agricultural fields to the south of Silver Peak both rely on the water resources of the Clayton Valley. Since this area is very arid, groundwater is the primary source of water for many of these activities and in the summer months, the landscape is

particularly dry, so more water is needed to meet the crop production demand. As both activities require significant amounts of water for productivity and efficiency, the recharge rates in the summer are low and demand is high, creating competition and further strain on the groundwater aquifer system.

Discussion

Due to the widespread lack of reported measurements for water balance and pumping rates associated with lithium extraction, this study aims to quantify the water storage and pumping rate at Silver Peak compared to a nearby basin in order to understand the relationship between lithium mining and water resource depletion in an area that already faces sufficient groundwater stress. Our methodology is very crude, so the results should not be considered perfectly accurate or exact. However, from each of the ranges, -25,209.44, -40,435.27, and -74,345.98, an estimate of the pumping rate is shown and highlight the scale of water extraction occurring at Silver Peak from OpenET data. By comparing these estimates to the published pumping rates from the SEC technical/pre-feasibility report, there may be a larger actual pumping rate than what was reported. As stated, even though these results are not exact, these results are promising and allow for room for improvement. This demonstrates that it is possible and feasible to estimate the water impact of lithium mining on groundwater systems using remote sensing data.

After collecting and analyzing the data to support a scaled-down water budget estimation, there are some uncertainties that should be addressed in future work. A key limitation of the study is that we focused on the area where the ponds were located, which is the bottom of the basin. The data collection was heavily limited and scaled down due to the limit on the area that could be collected through OpenET. In reality, a water budget would be made for the entire

watershed. However, this is the starting point for valuable quantifiable estimates of the impact of lithium mining on groundwater resources. Future work would be to expand this type of analysis to compare the whole Silver Peak watershed to adjacent watersheds. While this study is reasonable, the scope needs to be expanded to look at the impacts in a more realistic way. It is then that a more comprehensive and accurate water budget could be developed to allow for a more precise understanding of the impact of lithium mining.

Conclusively, this study has a lot of potential in paving the way for more comprehensive water budget analysis. Such analysis is crucial in order to accurately inform policymakers of this issue in order to implement adequate water management practices in regards to mining and water use in hypo-arid regions. By advancing our knowledge of the impacts of mining on water resources, we can figure out solutions in which we can balance the demand for critical minerals and the need to conserve pivotal water resources.

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