Identifying Potential Hydrologic Impacts of Lithium Extraction in Nevada

Daniel Saftner
Kevin Heintz
Ron Hershey

July 2023

Publication No. 41297

Prepared by
Division of Hydrologic Sciences, Desert Research Institute

Prepared for
The Nature Conservancy

THIS PAGE LEFT INTENTIONALLY BLANK

Identifying Potential Hydrologic Impacts of Lithium Extraction in Nevada

Daniel Saftner
Kevin Heintz
Ron Hershey

July 2023

Publication No. 41297

Prepared by
Division of Hydrologic Sciences, Desert Research Institute

Prepared for
The Nature Conservancy

THIS PAGE LEFT INTENTIONALLY BLANK

ABSTRACT

This report is to be used as an outline for a detailed and comprehensive examination and assessment of the potential impacts of lithium extraction on water resources in Nevada, including both surface water and groundwater. A Hydrologic Risk Assessment Checklist, or "Checklist," has been developed as a standardized approach to quantify the level of hydrologic risk of a proposed lithium mine and to compare the relative risk between lithium projects. Additionally, a Hydrologic Impacts Framework, or "Framework," has been developed for a more detailed evaluation of planned or future lithium mines in Nevada. Overall, hydrologic impacts from lithium extraction are a function of the lithium resource type (i.e., brine, clay, or rock), hydrologic and geologic conditions, and facility operations (i.e., scale of production, extraction technique, and processing technique). The Checklist and Framework lead the user through several critical questions pertaining to a lithium project's location, environmental conditions, design, and operational plan to identify the potential impacts on water resources. The results of applying the Checklist and Framework to a future lithium mine will identify areas of uncertainty with respect to potential hydrologic impacts.

Disclaimer: Neither the Checklist nor Framework should be used as a comprehensive review that covers all environmental risks or as an alternative to intensive, site-specific hydrologic impact assessments that precede regulatory approval. This work should be used by stakeholders as a starting point for their specific application to address uncertainty prior to detailed site-specific analyses.

ACKNOWLEDGMENTS

The authors would like to thank Jenny Chapman, Monica Arienzo, and Sean McKenna for their thorough reviews, Dave Decker for his comments, and Nicole Damon for her editorial support. The authors greatly appreciate the feedback and assistance from The Nature Conservancy, including Michael Clifford and Laurel Saito. Funding for this project was provided by a grant from The Nature Conservancy, which was donated by the E.L. Cord Foundation. This study was also made possible by the Division of Hydrologic Sciences at Desert Research Institute.

CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

°C	degrees Celsius
°F	degrees Fahrenheit
AMD	acid-mine drainage
BLM	Bureau of Land Management
BMPs	best management practices
$CaCO_3$	calcium carbonate
CaO	calcium oxide
CBD	Center for Biological Diversity
Checklist	Hydrologic Risk Assessment Checklist
DLE	direct lithium extraction
EPA	Environmental Protection Agency
FeCl	iron chloride

FEMA	Federal Emergency Management Agency
Framework	Hydrologic Impacts Framework
FoS	factor of safety
GDE	groundwater dependent ecosystem
H_2SO_4	sulfuric acid
HAI	hydrologic area of influence
HCl	hydrochloric acid
HCM	hydrogeologic conceptual model
HSU	hydrostratigraphic unit
IEEIRP	Independent Expert Engineering Investigation and Review Panel
INAP	International Network for Acid Prevention
Li^+	lithium ion
Li_2CO_3	lithium carbonate
LiCl	lithium chloride
LiOH	lithium hydroxide
Li_2SO_4	lithium sulfate
$Mg(OH)_2$	magnesium hydroxide
Na_2CO_3	sodium carbonate
NAC	Nevada Administrative Code
NDEP	Nevada Division of Environmental Protection
NDEP-BMRR	Nevada Division of Environmental Protection Bureau of Mining Regulation and Reclamation
NDOM	Nevada Division of Minerals
NP:AP or NPR	ratio of acid neutralizing potential to acid production potential
PVC	polyvinyl chloride
RIB	rapid infiltration basin
Thacker Pass	Thacker Pass Lithium Mine Project
TNC	The Nature Conservancy
US DOI	United States Department of the Interior
USFS	United States Forest Service
USGS	U.S. Geological Survey

THIS PAGE LEFT INTENTIONALLY BLANK

1.0 INTRODUCTION

1.1 Lithium Demand

As the United States and other countries shift from fossil fuels to renewable energy, more lithium will need to be produced to meet the increased demand for energy storage. In the contiguous United States, there are 72 proposed lithium extraction sites in nine states, which include Arizona, Arkansas, California, New Mexico, Nevada, North Carolina, Oregon, Utah, and Wyoming as of August 2022 (Parker et al., 2022). With 85% of the known lithium deposits in the United States, Nevada has the potential to be a key lithium producer (Parker et al., 2022). Lithium-containing brines, hard rock, and clay are the target geological settings for producing economical amounts of lithium. The mined lithium will be used primarily for energy storage in rechargeable batteries, which are widely used in electric vehicles and portable electronic devices.

1.2 Lithium Claims in Nevada

This report identifies potential hydrologic impacts associated with current or planned lithium mines in Nevada. To examine current lithium claim activity in Nevada, the Nevada Division of Minerals (NDOM) interactive map of Inferred Nevada Lithium Placer Claims was used (NDOM, 2023). The map was filtered to show active placer claims (Case Disposition = *Active Claims* and Claim type = *Placer Claims*) for claims filed since June 30, 2013. This filtering resulted in 14,545 active claims as of July 2023, an increase from 10,817 in July 2022 when the same filtering was applied by McKenna et al. (2022). A map created by the Center for Biological Diversity (CBD) reports 78 lithium projects in Nevada as of July 2023. Lithium project details are not explained on the CBD map, but they generally represent deposits where commercial interests have made an investment beyond the initial step of staking a claim (McKenna et al., 2022). In August 2022, The Nature Conservancy (TNC) completed a broad analysis and report on current and proposed lithium extraction in the United States (Parker et al., 2022). At the time of the TNC report, there were 40 proposed lithium extraction sites in 20 different valleys/regions of Nevada (Figure 1) where mining companies have a stated interest in producing lithium, including 15 sites in the Clayton Valley/Silver Peak region and five sites in Railroad Valley. Brine is the target resource type at 30 (75%) proposed extraction sites in Nevada, followed by six rock/clay targets, and two sites targeting both brine and clay (Parker et al., 2022). At locations targeting brine or both brine and clay, evaporative concentration is the proposed extraction method at 31 locations, whereas direct lithium extraction (DLE) with reinjection is proposed at one location (Railroad Valley South). The Clayton Valley Lithium Pilot Plant Project is expected to be the first attempt at DLE in Nevada. The pilot plant is used to test the approach to extracting lithium from underground brine resources without the need for evaporation ponds. The pilot plant returns fluid to the subsurface using infiltration basins, but if the project moves to full scale, then the intent is to use injection wells. At the six sites targeting rock/clay lithium resources, open-pit mining is proposed at three locations, whereas the remaining locations propose strip mining.

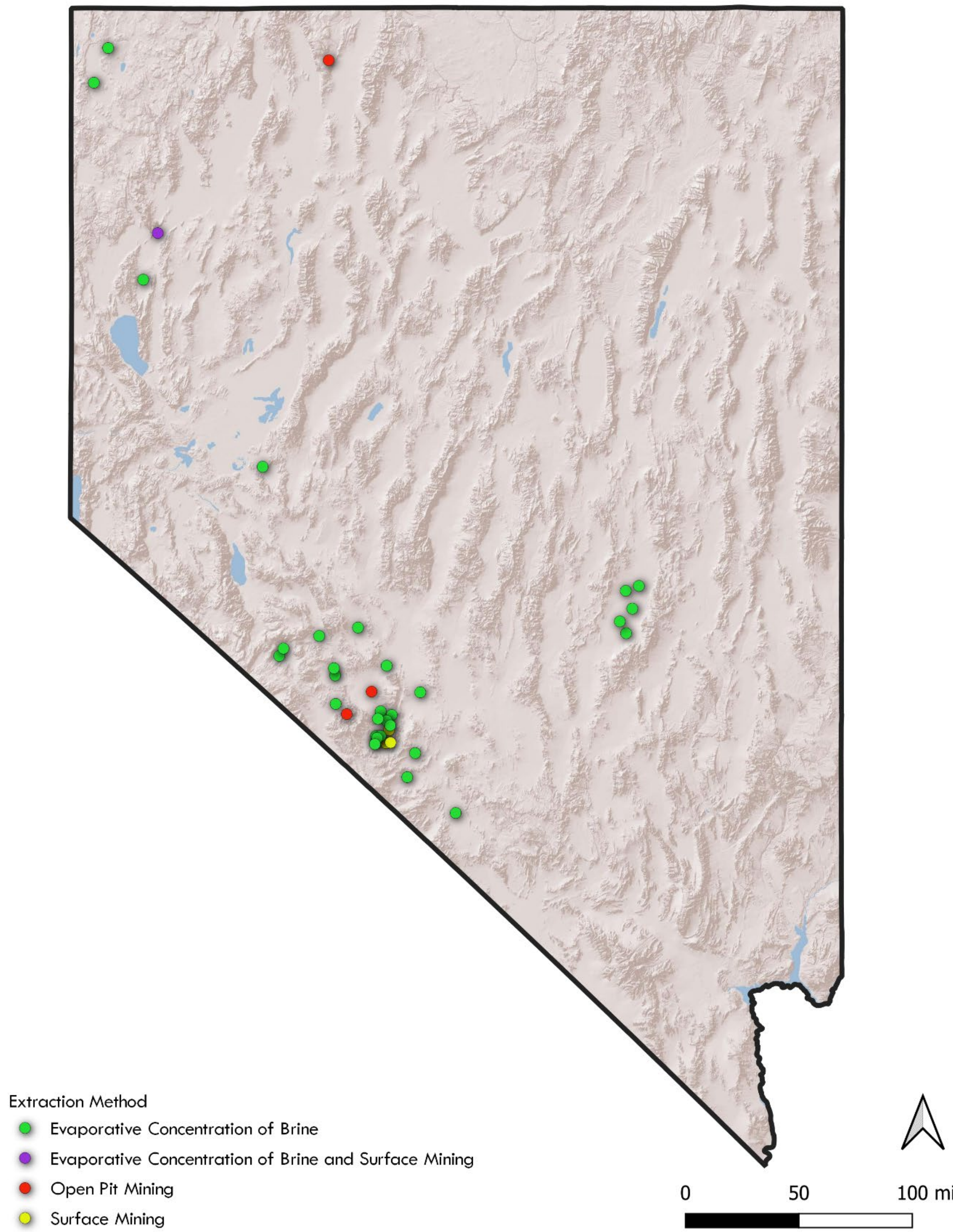

Figure 1. Map of proposed lithium extraction sites (colored by extraction method) in Nevada as of August 2022. Modified from Parker et al. (2022).

1.3 Lithium Formation: Geology and Hydrology

Concentrated lithium occurs naturally in three types of geologic materials that are economically viable: mineral ores, clays, and brines. Mineral ores (or "hard rock") containing concentrated lithium are pegmatite formations, which are coarse-grained igneous intrusions. Spodumene, lepidolite, and petalite are the most commonly observed lithium-bearing pegmatite minerals (Brown et al., 2016). The presence of lithium in magmatic bodies is likely a function of the melted source material, magmatic-hydrothermal fluids, temperature, pressure, and fractional crystallization (Brown et al., 2016). Eventually, weathering and erosion of ore bodies can result in the transport and deposition of lithium-bearing materials. To form lithium-bearing clay, accumulated particles undergo diagenesis (changes in mineralogy and texture by physical, chemical, and biological processes during rock formation) and hydrothermal alteration, in which chemical reactions convert the parent material. Thacker Pass Lithium Mine Project (Thacker Pass) in northern Nevada exemplifies this scenario, where volcanically derived sediments (including ash) concentrated in a closed, arid basin were hydrothermally altered into lithium-rich hectorite clays (Bradley et al., 2017; Rytuba and Glanzman, 1979).

Lithium brines form in arid basins that contain a salt lake or salt "crust" (a hard and dry salt surface that forms when salts are left behind after water is evaporated), igneous or geothermal activity, and proximal lithium sources (Munk et al., 2016). A number of processes contribute to continental brines containing lithium compounds, commonly lithium chloride (LiCl) and lithium carbonate (Li_2CO_3). Munk et al. (2016) suggest that magmatic fluids deliver lithium directly from shallow magma sources to groundwater. Lithium is highly soluble and easily mobilized by surface water and groundwater once weathered from its parent material. Lithium may also be deposited in the basin by windblown dust or volcanic ash. Lithium within the basin can then be concentrated via evaporation and interactions between hydrothermal fluids and the host aquifer (Bradley et al., 2017). Hydrothermal activity enables brine circulation that moves deep lithium-rich brines upward (Munk et al., 2016). The brine composition is dependent on groundwater recharge and the geochemistry of the parent and basin-fill material, and compositions can range from highly saline groundwater dominated by evaporite deposits to brines characteristic of younger sediments with greater recharge (Munk et al., 2016). Overall, a combination of mechanisms accounts for the lithium observed in continental brines.

Lithium is closely tied to the hydrology of Nevada, both as a result of the mechanisms by which lithium deposits occur and the processes used to extract lithium. Lithium is transported by surface water and groundwater, and lithium-bearing brines are formed by the hydrologic processes that influence the geochemical composition of arid basins. Lithium can be sequestered from brines by natural mineral precipitation, industrial mining, or at hydrothermal zones where lithium-bearing clays crystallize. The effects of brine extraction in Nevada may include direct, indirect, or cumulative impacts that alter the quantity and quality of local and regional water resources.

1.4 Intents, Purposes, and Limitations

The Hydrologic Risk Assessment Checklist (Checklist) identifies the areas of greatest concern when evaluating hydrologic-based environmental risks of a proposed lithium extraction facility. It is concise and enables the identification of potential hydrologic risks, or "red flags," and areas with substantial uncertainty. The Checklist provides a standardized approach to aid stakeholders in assessing the potential risk of a single proposed lithium facility or comparing relative risk between separate proposed facilities. It focuses on the major hydrologic risks associated with land disturbances, resource extraction, resource processing, and waste management encountered at a typical lithium project that is in the planning phase. The Checklist does not consider measures for monitoring, mitigation, modeling, facility closure, or post-facility closure with respect to hydrology that are all necessary components to assess a project's potential environmental impact, predict and observe conditions that threaten water quantity or quality, and ensure long-term protection of water resources. These items are included in the more elaborate Hydrologic Impacts Framework (Framework).

The Framework is designed to inform decision-making related to potential surface-water and groundwater impacts from lithium extraction and processing in Nevada. Like the Checklist, the Framework has not been developed for a specific lithium facility. Rather, it has been designed to evaluate typical circumstances that may arise during lithium extraction projects with specifics by resource type and processing technique. It is meant to be adaptable so that alternative actions or revisions to the extraction plan can be assessed. This Framework assessment accounts for impacts associated with project design, lithium extraction, lithium processing/refining, and facility closure/post-closure activities and does not consider impacts specific to exploration activities or off-site processing. Critical questions and areas of uncertainty identified by applying the Framework may be used for further evaluation during exploration or project-design activities. Hydrologic impacts associated with underground mines are not described in detail in this assessment because there are currently no proposed underground lithium mines in Nevada, and underground mining for lithium is unlikely to occur in the state (Parker et al., 2022). Hydrologic impacts associated with in situ leach mining are also not considered because no known proposed or ongoing lithium operations use this method.

Neither the Checklist nor Framework should be used as a comprehensive review that covers all environmental risks or as an alternative to intensive, site-specific hydrologic impact assessments that precede regulatory approval. Instead, the Checklist and Framework may be used to identify areas of uncertainty related to the potential for hydrologic impacts associated with lithium extraction. After applying these tools, more detailed site-specific analyses should be considered and implemented to address the areas of uncertainty. Additional impacts not foreseen by this effort may be discovered upon applying this outline to a specific lithium-extraction operation and those impacts should then be included upon discovery. This report does not consider potential impacts of extraction on related systems, including biology, ecology, air quality, economic, etc., and therefore does not address unintended and unforeseen long-term hydrologically dependent impacts, which were outside the scope of this work. The Checklist and Framework may be paired with other assessments to identify areas or waters of concern (e.g., pairing with an ecological assessment to identify aquatic habitat that may be at risk). Finally, this work does not offer guidance on what constitutes a complete or correct response to any of the questions in the Checklist or the Framework - such decisions are left to the stakeholders who use this document as a starting point for their specific application.

2.0 METHODOLOGY

2.1 Literature Review

A literature review was conducted on the environmental conditions for lithium formation, lithium extraction techniques, and hydrologic-based environmental impacts of lithium extraction specific to Nevada's surface waters and groundwaters. The review included technical reports, regulatory documents, and peer-reviewed research papers, which are cited throughout this document. Regulatory agencies, including the Nevada Division of Water Resources, the United States Forest Service (USFS), the Bureau of Land Management (BLM), and the Nevada Division of Environmental Protection (NDEP) have existing permitting requirements for mines in the state of Nevada. Because of the potential of lithium extraction activities to degrade surface waters and groundwaters, all lithium-extraction and exploration activities in Nevada are subject to the regulatory permitting program of the NDEP Bureau of Mining Regulation and Reclamation (NDEP-BMRR).

2.2 Ideal Scenario for Minimizing Hydrologic Impacts

Lithium extraction is always likely to have some hydrologic impact, but some situations will have fewer impacts than others. The "ideal scenario" that is expected to minimize hydrologic impacts related to lithium-extraction and processing activities was conceptualized to help develop the Checklist and Framework. The ideal scenario considers environmental, operational, and monitoring/mitigation conditions. The ideal scenario assumes that DLE processing techniques have the lowest potential for hydrologic impacts because DLE can 1) be integrated into existing infrastructure and 2) use less freshwater than evaporative techniques. However, it has not been proven that DLE technologies use less freshwater and minimize hydrologic impacts because they are still under development and have not been implemented at commercial scales. The ideal scenario would meet the following criteria:

1. **Resource type and processing method:** Lithium-containing brine is the resource type. The lithium is removed from the brine using DLE processing methods that minimize water usage/losses and adverse impacts on water quality during extraction, processing, and reinjection.
2. **Infrastructure and disturbance:** Direct lithium extraction is integrated into existing facilities, such as geothermal power plants where geothermal brine also contains lithium, and no new land disturbance is required.
3. **Brine extraction:** Brine is already being pumped at the pre-existing facility at volumes and/or rates that will satisfy requirements of the existing operation and meet lithium requirements. No supplemental pumping is required for lithium-related operations, extraction, or processing. For example, technologies are being developed to extract lithium and other elements from geothermal fluids (Stringfellow and Dobson, 2021; Simmons et al., 2018).
4. **Hydrogeologic setting:** Brine is pumped from an aquifer that is hydraulically disconnected from the neighboring aquifers and surface waters, thereby causing little to no adverse impacts on waters and ecosystems (determining the extent to which this is true requires existing data for groundwater and surface water and a comprehensive hydrogeologic conceptual model). Brine is reinjected into the original aquifer, with

minimal changes to the original surface-water and groundwater levels and quality (requires that baseline conditions are established and that a monitoring program is in place).

2.3 Establishing the Hydrologic Risk Assessment Checklist and Framework

The Checklist was compiled during development of the Framework to identify hydrologic risks for lithium-extraction facilities. Areas or topics from the Framework that are considered to have higher potential for hydrologic-based environmental impacts are included in the Checklist.

The Framework starts with general questions about hydrology and hydrogeology that pertain to all future lithium projects in Nevada that use or may impact surface water or groundwater independent of resource type and extraction technique. The Framework then moves into specific questions to be considered for each resource type and extraction technique. The sections of the Framework occur in chronological order of the project activities, from pre-disturbance (before any land disturbance or lithium extraction) to post-facility closure. An outline of the Framework and associated discussion is provided here:

- Pre-disturbance surface-water hydrology**:** What is known about surface-water conditions (including water quality and quantity/flow) prior to any land disturbance and extraction activities? This section applies to **all resource types** (i.e., brine, clay, and hard rock) and **all extraction methods** (i.e., evaporative concentration, DLE, surface strip mining, surface pit mining) relevant to Nevada.
- Pre-disturbance groundwater hydrology**:** What is known about groundwater and aquifer conditions (including water quality and quantity/flow), and underlying geology prior to land disturbance and extraction activities? This section applies to **all resource types** and **all extraction methods** relevant to Nevada.
- Land disturbances and infrastructure: What are the potential hydrologic effects of land disturbances and new or modified infrastructure? This section applies to **all resource types** and **all extraction methods** relevant to Nevada.
- Resource extraction and facility operations: What are the hydrologic effects of resource extraction and facility operations? This section identifies **specific hydrologic impacts by resource type**, distinguishing between brines and clays/hard rock.
- Resource processing: What are the hydrologic impacts of resource processing? This section identifies **specific hydrologic impacts by processing method**, including evaporative concentration and DLE for brines, and strip mining and open-pit mining for clays/hard rock. Specific considerations are made to distinguish between potential impacts on water quality and water quantity.
- Facility closure: What are the potential hydrologic impacts incurred during facility-closure activities? This section applies to **all resource types and extraction methods,** with some specifics by resource type.
- Post-facility closure**:** What are the potential hydrologic impacts incurred after permanent facility closure? This section applies to **all resource types and extraction methods,** with some specifics by resource type.

3.0 Lithium-Extraction Techniques and Potential Hydrologic Impacts

Various techniques exist for extracting lithium from the host material, including evaporative concentration and DLE from brines, and surface mining (i.e., strip mining and open-pit mining) and underground mining to extract lithium from hard rock and clay. Lithium may be refined at the extraction facility into the final product, which is commonly battery-grade Li_2CO_3 or lithium hydroxide (LiOH) used for lithium-ion batteries or sent elsewhere for refinement. Hydrologic impacts may vary depending on the resource type, extraction technique, and environmental conditions (i.e., hydrology, geology, and climate). This section provides an overview of the extraction techniques and the potential hydrologic impacts associated with each. Each method may vary from site-to-site depending on the local environmental, resource, and operational conditions. For the purpose of this report, the focus is on the general methodologies that are commonly used.

3.1 Evaporative Concentration of Lithium Brine

The evaporative concentration technique for extracting lithium from brines relies primarily on open-air evaporation to concentrate lithium. Brines are pumped via wells from underground reservoirs into open-air ponds to induce evaporation. The extraction of brine from reservoirs that are hydraulically connected to adjacent aquifers or surface waters may have adverse impacts on the water quality and/or quantity of neighboring water resources and groundwater dependent ecosystems (GDEs). As the lithium-bearing brine is pumped, it lowers the hydraulic head in the aquifer, creating a cone of depression (i.e., an artificially lowered groundwater level) around the well(s). Groundwater flows from regions of high head to low head, so flow will be induced toward the extraction wells. Depending on aquifer conditions, this can lower water levels in surrounding areas and reduce discharge to springs. If the water drawn toward the brine reservoir has lower concentrations of dissolved solids and metals, it may be degraded by mixing with the brine. These effects are largely controlled by characteristics of the brine aquifer, including aquifer geometry and hydraulic properties (i.e., hydraulic conductivity and storage parameters), the hydrologic budget (i.e., groundwater and surface-water inflows and outflows), and design of the extraction-well field (e.g., locations, depths, screened intervals, casing diameters, and target pumping rates).

Once the brine has been pumped from the subsurface, a system of evaporation ponds is typically used to evaporate water and precipitate unwanted minerals that crystallize in sequence with the use of various additives. For example, calcium oxide (CaO) is commonly used to induce the precipitation of magnesium minerals. Dissolved LiCl remains in the brine, whereas more than 90% of other salts crystallize and settle out in the ponds. Crystallized salts may be dredged and stored or mixed with water and reinjected into the subsurface. Mixing may require additional freshwater and injecting a concentrated brine (reinjection methods and associated hydrologic impacts are described in later sections). The volume of water lost to evaporation is a function of several environmental and operational factors. The ratio of evaporative water loss per ton of lithium produced is directly related to the concentration of lithium in the extracted brine. Low-concentration brines require more water to be evaporated per ton of lithium salt produced than higher-concentration brines, such as those located in Chile. Generally, more than 90% of the original water volume is lost through the evaporation process (Vera et al., 2023). This consumptive use is of particular concern in arid regions where natural water deficits are exacerbated by human influences.

An important factor in pond design is to minimize leakage into the subsurface by siting ponds where there is an extensive layer of low-permeability clay beneath the pond, which requires a thorough soil survey (Garret, 2004). If the clay layer occurs at a great depth, then the outer pond walls may be trenched and filled with low-permeability materials. Zones of permeable soil may be removed and backfilled with clay. The initial evaporation ponds in Clayton Valley, Nevada, leaked excessively because of the presence of highly permeable soils (Garrett, 2004). As an alternative or additional measure, evaporation ponds may be lined with plastic membrane barriers, though these can potentially fail and allow high-salinity brines to infiltrate the subsurface (Wanger, 2011). Moisture sensors, electrical conductivity sensors, and piezometers should be placed in the underlying soil to detect leaks.

Once the evaporation stage is complete, the concentrated brine is transferred to a refining plant, which may be located at the extraction facility or an off-site facility, for removal of remaining impurities and producing the final lithium product. Freshwater is used at many stages of the evaporation and refining processes, including dissolving additives, scrubbing organic solvents, washing Li_2CO_3 crystals, and for steam generation (Vera et al., 2023). Meeting the freshwater demand may require the use of local groundwater and surface-water resources. Freshwater extraction from local resources may affect groundwater levels in freshwater aquifers, lake levels, and discharge of streams and springs. Again, the magnitude of these effects depends on the hydrologic and hydrogeologic conditions, well design and location, and extraction rates.

3.2 Direct Lithium Extraction from Brine

Direct lithium extraction relies on chemical and physical separation of lithium ions from the brine. As with evaporative concentration, DLE requires pumping brines from the subsurface, which can lead to the same hydrologic consequences outlined for evaporative concentration techniques. There are several potential advantages to DLE over evaporative concentration, all of which have direct or indirect hydrologic benefits, including 1) co-location with existing industrial facilities and processes, 2) reduced land disturbance, 3) faster lithium production, 4) the potential to make low-grade lithium economically viable, and 5) the potential to produce battery-grade lithium products at the point of extraction. In terms of total water consumption (brine plus fresh processing water), DLE can use less than conventional evaporation because there is limited or no need for evaporation ponds and some of the water/brine is returned to the subsurface. However, some DLE techniques may consume more freshwater than evaporative techniques (Vera et al., 2023).

Several DLE technologies have been developed over recent years and there are DLE facilities proposed for Nevada, including the Clayton Valley Lithium Pilot Plant Project. Vera et al. (2023) classify DLE technologies into seven general categories, including ion-exchange resins, solvent or liquid-liquid extraction, electromembrane processes, nanofiltration, electrochemical ion-pumping, selective precipitation, and thermal-assisted methods. The hydrologic footprint of each method varies with respect to water usage and potential for contamination. Ion exchange and electrochemical ion-pumping usually require freshwater or acidic solutions to desorb lithium cations from resins to produce a concentrated lithium solution (e.g., LiCl). Organic solvents require additives that have a high affinity for lithium ions (Li^+) (e.g., tri-n-butylphosphate, iron chloride [FeCl], or ionic liquids), mixing with an aqueous phase to liberate the Li^+ cations, and pH changes. Selective precipitation relies on the addition of different phosphates to recover lithium from brines. Solar evaporation is a thermal-assisted method with the objective of concentrating brines while maximizing the recovery of evaporated water.

Freshwater inputs are required for several DLE techniques and can be higher than evaporative concentration for extracting lithium. Vera et al. (2023) reviewed 57 academic articles from the period 2017-2022 for freshwater requirements of ion pumping, solvent extraction, ionic-exchange resins, and Li^+ insertion electrodes, all of which require freshwater for Li^+ elution from a sorbent phase. Compared to the freshwater consumption using evaporative technology at the Salar de Atacama (22.5 m^3 [5,950 gallons] of freshwater consumed per ton of Li_2CO_3 produced) and Salar de Olaroz (50 m^3 [13,000 gallons] of water per ton of Li_2CO_3) in Chile, 13 studies used less freshwater, 9 used similar amounts, approximately 14 used more than ten times the amount of freshwater, and the remainder did not provide freshwater consumption data. A full-scale DLE operation at the Salar del Hombre Muerto uses a total of 71 m^3 [19,000 gallons] of freshwater per ton of Li_2CO_3. Kaunda (2020) estimated that 1,900 m^3 (500,000 gallons) of water are lost to evaporation per ton of lithium extracted. This large variance in evaporative loss depends on the concentration of the original brine. A recent focus has been placed on water recovery while concentrating brines using DLE methods, such as membrane distillation. In summary, DLE techniques commonly require freshwater inputs; many techniques may consume more freshwater than existing evaporative techniques, but advances are being made to condense and capture the water vapor produced during evaporation.

Once lithium has been extracted, the lithium-depleted brine ("spent brine") is typically reinjected back into the original reservoir (methods of reinjection are described in later sections). The reinjection process can have hydrologic impacts that include altering pore-water pressures and the natural groundwater physical and chemical conditions (Flexer et al., 2018). From a production perspective, reinjection of spent brines may also dilute the lithium resource (Flexer et al., 2018). Spent brines likely contain chemical species from the DLE process and pH levels that are different from the original brine. Few studies report findings related to the reinjection of spent brines, but underground injection of brines and other fluids has a long history in the oil and gas development industry. The primary alternative to reinjection includes open-air evaporation of brines, which leads to greater water losses.

3.3 Surface Mining of Hard-Rock and Clay Deposits

Surface-mining processes for hard rock or clay vary based on site-specific conditions but will generally involve overburden removal to expose lithium-bearing material in a strip mine or open-pit mine. This will include excavation using heavy equipment and drilling and blasting followed by transportation of ore to a processing facility for separation, extraction, and refinement. Beneficiation techniques may be used, such as mechanical crushing and grinding as well as flotation, magnetic separation, and/or gravity separation. Non-lithium bearing material, such as soil and waste rock, are usually stored in stockpiles and potentially used later to backfill the excavated area. Waste-rock piles are usually designed to drain freely and are commonly constructed with engineered drainage systems (US EPA, 1997). Tailings are the fine-grained waste material resulting from the grinding, processing, and recovery stages that are commonly deposited on the surface behind a structural zone (embankment) in a tailings pond or impoundment. Alternatively, a thickening material is used as an additive to help bond materials, which are then filtered and dried into a “cake” and piled on the surface (i.e., a stack).

Extraction techniques for both hard rock and clay were reviewed by Meshram et al. (2014). These methods commonly use a pre-treatment roasting procedure during which high temperatures (300 °C to 1100 °C [570 °F to 2,000 °F]) enable chemical transformation through acid or alkali digestion. Acid-digestion treatment uses sulfuric acid (H_2SO_4) and water to form lithium sulfate (Li_2SO_4), which is filtered and purified to remove solid waste and other metals. The concentrate is then combined with sodium carbonate (Na_2CO_3) to ultimately precipitate Li_2CO_3. Less commonly, hydrochloric acid (HCl) is used instead to generate a LiCl solution. Alkali digestion uses calcium carbonate ($CaCO_3$) in the roasting process, then water leaching yields LiOH, which can then be converted to Li_2CO_3.

There is currently no production-scale facility extracting lithium from clay deposits anywhere in the world. Thacker Pass is the prototype for lithium extraction from clay and the project began construction in 2023. The Thacker Pass Feasibility Study (Lithium Americas Corp., 2022) summarizes the processing of lithium-bearing clay using a H_2SO_4 leach that is then neutralized with $CaCO_3$ and magnesium hydroxide ($Mg(OH)_2$) and undergoes subsequent decantation/filtration and removal of magnesium and calcium. Ion-exchange polishing acts to decrease the cation concentration prior to Li_2CO_3 purification (including sulfate and salt removal) and production. Neutralized filter cake and sulfate salts will be deposited at a clay-tailings, dry filter stack where the tailings are underlain by a liner and drainage system to contain material and prevent the infiltration of fluid into the subsurface.

Water quantity and quality may be adversely affected by hard-rock/clay mining through a variety of mechanisms, many of which are specific to the facility operation and the local hydrology, geology, climate, and hydrogeology. Water usage can affect groundwater levels, stream and spring discharges, lakes, and wetlands if water is consumptively used. Ore extraction may be near or below the water table and require groundwater pumping for dewatering that perturbs groundwater flow paths and can result in a cone of depression. Upon cessation of dewatering, a pit lake (i.e., water that partially or completely fills an open pit) may form and contain contaminants and be hydraulically connected to groundwater. Mining operations have freshwater requirements at various stages of construction, extraction, transportation, and processing. For example, the Thacker Pass Environmental Impact Statement (US BLM, 2020) reported the expected water usage for operations (including dewatering) is 3,200,000 m^3/year (2,600 acre-ft/year) for the first four years, then 6,400,000 m^3/year (5,200 acre-ft/year) for the remaining duration of the project (i.e., approximately 40 years).

The United States Environmental Protection Agency (US EPA, 1997) outlined the potential surface-water and groundwater impacts caused by hard-rock mining for metals, and Smith (2021) expanded on groundwater impacts at hard-rock mining sites. Surface mining causes alterations to the topography that may intersect perennial surface water, shallow groundwater, and springs, and/or affect stormwater runoff conveyance causing increased erosion and sedimentation if not properly mitigated. Pollution of surface water, soils, and groundwater is possible because of the occurrence of explosive chemicals and combustion byproducts, the use of acidic and basic compounds, and heavy metals and metalloids that may leach into the environment from exposed materials at waste-rock disposal sites, tailings, waste streams, and pit-lake/mine-water areas. Such constituents may be introduced to water resources via surface runoff (either in suspended sediment, dissolved in surface water, or both), leaching from soil or impoundments into surface water or groundwater, or direct mixing with groundwater in ponds that are at, or below the water table. Chemical substances that are considered contaminants of concern are defined under the Clean Water Act (https://www.epa.gov/eg/toxic-and-priority-pollutants-under-clean-water-act#toxic). The prevalence and concentration of these substances may be highly variable across different timescales and dependent on a number of factors, such as climate, geochemistry, and operational procedures, among others. A major concern in common hard-rock mining applications is acid-mine drainage (AMD) that leads to contaminant mobilization if sulfide minerals are extracted and weathered.

4.0 HYDROLOGIC RISK ASSESSMENT CHECKLIST

4.1 Using the Checklist

The information below complements, and should be used with, the Checklist (Appendix A), providing additional details for consideration. The Checklist is a series of questions that require Yes/No responses, with **a "Yes" response indicating greater hydrologic risk than a "No" response**. Generally, the potential for hydrologic risk increases with the total number of "Yes" responses for the project under evaluation. The Checklist provides a space for notes to allow the user to capture nuances, complications, or observed factors that may supplement the "Yes" or "No" response. **If the answer to a question is unknown because of a lack of site characterization or there is high uncertainty, it should be marked as a "Yes" to represent risk.** Further investigations (e.g., data collection, testing, etc.) should be conducted to reduce uncertainty. Appendix A includes three checklists:

- The General Hydrology Checklist (Table A-1) is to be completed for all lithium-resource and extraction types (i.e., brine extraction and surface mining). This checklist provides a list of general questions used to identify general hydrologic risks associated with any lithium extraction operation in Nevada.
- The Lithium Brine Checklist (Table A-2) applies to both DLE and evaporative concentration techniques associated with lithium-brine operations. This checklist should be completed in addition to the General Hydrology Checklist.
- The Surface Mine Checklist (Table A-3) applies to both strip mining and open-pit mining of clays and hard rock. This checklist should be completed in addition to the General Hydrology Checklist.

To complete the Checklists, the user should:

- Collect all documents relevant to the proposed or planned lithium extraction facility (e.g., plan of operations and environmental assessments).
- Collect available maps (e.g., water features and facility design).
- Develop a hydrogeologic conceptual model (defined below).
- Define the hydrologic area of influence (defined below).

A hydrogeologic conceptual model (HCM) is a simplified representation of the system of interest and includes site-specific information on physiographic, geologic, climatologic, and hydrologic parameters (Anderson et al., 2015). An HCM can be used to make qualitative assessments of hydrologic impacts related to groundwater stresses (e.g., lithium-brine extraction) and can be incorporated into an analytical or numerical groundwater flow model to quantify spatial and temporal hydrologic effects associated with a lithium extraction facility and associated uncertainty. The development and application of groundwater flow models is beyond the scope of this assessment, but NDEP-BMRR (2021a) provides guidance for hydrogeologic groundwater flow modeling at mine sites in Nevada (https://ndep.nv.gov/land/mining/regulation/guidance-policies-references-and-requirements).

The hydrologic area of influence (HAI) defines the spatial extent where hydrologic impacts associated with lithium extraction activities are expected to occur, which may be determined qualitatively from the development of the HCM or quantitatively using numerical modeling. The HAI is defined based on site-specific hydrology and hydrogeology data, as well as facility operations. In the absence of these data, the extent of the HAI would be approximated by the surface-water drainage basin, with the potential for that to be reduced or expanded in size as site data are gathered. Additional information to be considered for each risk assessment question in the Checklist is provided below.

4.1.1 General Hydrology Checklist (Table A-1)

1. **Springs and seeps** – Springs and seeps that are present in the HAI could be impacted directly by the facility land features or by groundwater extraction that may reduce spring flow, impact GDEs, and compromise water quality. This includes springs that are perennial or intermittent. Highly disturbed springs (e.g., stock ponds) and ephemeral springs do not qualify here because they do not have flow that can be affected by water extraction (see Section 5.1.1 #3 for definitions of perennial, intermittent, and ephemeral).
2. **Geothermal springs** – Geothermally heated springs ("hot springs") often sustain unique and rare ecosystems that may be at high risk from hydrologic impacts associated with lithium extraction activities. Geothermal springs generally have perennial flow and receive at least some portion of inflow from deeper and/or regional geothermal groundwater that migrates to surface through faults and fractures. Geothermal water commonly mixes with shallow groundwater and meteoric water (i.e., recent precipitation) as it approaches the surface. The degree of water mixing adds complexities to identifying sources of water that should be considered. It is noted that geothermal springs, which receive inflows from deep, regional aquifers, may not be affected if there is no pumping directly from the regional aquifers.
3. **Spring and seep proximity to operations** – This question pertains to either the topographic gradient or the groundwater flow direction based on hydraulic gradient (i.e., slope of the water table or potentiometric surface), in which a "Yes" represents at least one affirmative. Springs and seeps that are topographically downgradient, such as in a valley below facility operations, may have a higher potential for being affected by surface-water erosion, sedimentation, or pollution caused by lithium

extraction. Springs and seeps may be hydraulically downgradient from a groundwater aquifer that is underlying project facilities and sensitive to upgradient activities (i.e., groundwater pumping or contamination).

4. **Other surface waters** – Streams, rivers, lakes, or ponds identified through baseline hydrologic studies that are present in the HAI could be impacted directly from the facility operations or by groundwater/brine extraction that may reduce streamflow or lake levels, impact GDEs and riparian zones, and compromise water quality. This includes water bodies that are perennial or intermittent. Ephemeral drainages and dry features (i.e., playas) do not qualify here because they do not have flow that can be affected by water extraction.
5. **Surface-water proximity to operations** – Like #3 above, this subsection pertains to surface-water bodies (including perennial or intermittent streams, rivers, lakes, or ponds) that are downgradient of site facilities.
6. **Groundwater dependent ecosystems** – Groundwater dependent ecosystems can include wetland and riparian areas that are supported by spring flow, streams, or shallow groundwater. The GDEs may not be explicitly mapped in environmental project documents, but potential GDEs may be identified by reviewing an aquatic resources study (if available) or using mapped indicators of GDEs, as reported by Saito et al. (2020). Wetland delineations may be performed to identify wetlands and establish wetland boundaries. Operations that may affect GDEs by altering water quality or quantity present a high hydrologic and ecologic risk because GDEs serve to naturally mitigate flooding, balance stream sediment supply, retain surface water and groundwater, and provide habitat for rare or endemic species of plants and wildlife.
7. **Project area footprint** – The entirety of the proposed or permitted project area is considered here. A project with a larger footprint introduces greater hydrologic risk because of the expanse of land disturbance, increased potential interactions with surface-water features, drainages, or depositional areas and widespread potential pollution sources. An overall footprint of 20.2 km^2 (5,000 acres) is based on the average site size (n=22) for proposed lithium extraction sites in Nevada using the Proposed Lithium Extraction Sites spreadsheet from Parker et al. (2022) (https://tnc.box.com/s/2qc3h5o1n4v693dt9l0ppwi8rw1jvdbe). The 20.2 km^2 (5,000 acres) footprint enables relative comparison between proposed lithium projects. The proposed or permitted project area should not be confused with the "surface disturbance footprint," which may also be listed on project documents, but is usually much less than the overall project area.
8. **Floodplains, erosion, sedimentation** – Facilities built within a Federal Emergency Management Agency (FEMA) designated floodplain are susceptible to flooding, erosion, sedimentation, and overtopping. Projects with relatively large amounts of geologic material that is excavated and stored present greater risks for slope failure, which can cause a sudden release of material leading to erosion and sedimentation, as

well as the potential for uncontrolled release of contaminants. A conservative factor of safety (FoS) is 1.5 for slopes, where a lower FoS presents greater risk. The recommended slope ratio measured by horizontal to vertical distance (H:V) is 5H:1V or better (e.g., 7H:1V) (Morrill et al., 2022).

9. **Groundwater-surface water connection** – Groundwater pumping alters the natural groundwater flow system by artificially lowering the water table, which can affect the levels and flow of connected surface waters. Surface waters in Nevada with perennial and intermittent flow commonly rely on groundwater to sustain baseflow. The magnitude of surface-water responses to groundwater pumping will depend on the hydraulic properties of the aquifer and connectivity of groundwater to surface water, which can vary over time (e.g., seasonal increase in the water table).
10. **Proximity to freshwater aquifers** – Facilities located near a shallow freshwater aquifer present a greater risk of groundwater contamination relative to projects where groundwater is deeper and/or saline or brackish. Freshwater is water containing total dissolved solids less than 1,000 ppm (USGS, 2018). A project is considered "near" groundwater if less than 30.5 m (100 ft) separates the water table from any facility (not including wells), per Nevada Administrative Code 445A.433 (NAC, 2022).

4.1.2 Lithium-Brine Checklist (Table A-2)

1. **Adjacent aquifers** – The extraction of brine from subsurface reservoirs/aquifers that are hydraulically connected to adjacent aquifers may have adverse impacts on the water quality or quantity/flow of these neighboring aquifers. Groundwater flows from areas of high hydraulic head to low hydraulic head—as the head is reduced in the pumped aquifer, this may induce flow toward the brine aquifer from neighboring aquifers, lowering water levels in those neighboring aquifers. If the water drawn toward the brine aquifer is of superior quality, it may be degraded by mixing with the brine.
2. **Chemical additives** – The on-site storage and use of chemicals during processing pose risks to water quality if not managed, stored, used, and transported properly and in accordance with the Site Safety and Security Plan. Chemical additives may be used for the removal of unwanted chemical constituents from the brine, pH adjustment, and chemical conversion of lithium compounds. The presence and use of chemical additives can have direct and negative impacts on surface water in the event of a spill and may infiltrate into the subsurface and contaminate groundwater.
3. **Evaporation and storage ponds** – Evaporation ponds are used to assist the lithium concentration process and can impact water quality and quantity. Multiple ponds are commonly used to promote evaporation and precipitate and remove unwanted minerals. More than 90% of the original water volume may be consumed through evaporation and is not returned as part of the groundwater budget. Ideally, ponds have impermeable bases and walls (natural clays or synthetic membranes) that prevent leakage. However, it is common for leaks to occur, allowing brine to infiltrate into the

subsurface and contaminate groundwater. Direct lithium extraction facilities may use storage ponds to limit brine volume changes. Storage ponds may present some of the same questions and risks, albeit at a smaller scale than an evaporation pond.

4. **Land subsidence** – Pumping from an aquifer or aquitard can lead to land subsidence. When water is withdrawn, the aquifer material compacts and can collapse in on itself. The degree of aquifer collapse and land subsidence is controlled in part by the geologic material. For example, clay and silt layers can fail structurally because of pumping. Dissolution of aquifer materials by injection of acidic fluids could also lead to land subsidence.
5. **Solid waste/by-products** – Solid waste/by-products may form during DLE and evaporative processes that require proper management, storage, and treatment. For example, crystallized salts that sink to the bottom of an evaporation pond may be dredged, transported, or stored and may even be mixed with freshwater and reinjected into the subsurface. Coagulants may be used for some DLE techniques to produce solids that are removed from the solution and may be transported to a local landfill.
6. **Rapid infiltration basins** – Rapid infiltration basins (RIBs) are commonly used in Nevada to reinfiltrate water and spent brines into the subsurface. The construction of a RIB facility and its use during operations can have direct impacts on groundwater quality and quantity and may also impact connected surface waters. The use of RIBs commonly concentrates recharge in a small area, which can produce localized zones of elevated groundwater levels. This phenomenon is referred to as a "groundwater mound." Rapid infiltration basins tend to pose a greater hazard to water quality and quantity than injection wells because groundwater mounds may temporarily alter groundwater flow paths and baseflow to connected surface waters. Injection wells tend to put fluids into deep zones that are often isolated from surface waters and associated ecosystems. The quality of the brine and water that is returned to the subsurface should match the quality of the targeted receiving brine and freshwater reservoirs. This includes all impacted subsurface reservoirs, including shallow freshwater and deep brines. The use of RIBs poses a great risk to water quality if residual brine is added to shallow groundwater of superior quality or if the infiltrated brine mobilizes chemicals (e.g., arsenic) in the unsaturated zone.
7. **Groundwater budget** – To maintain the groundwater budget, the volume of water or brine returned to an aquifer (via RIBs or injection well) must equal the volume removed. However, this is rarely achieved, as some ratio of a brine's original water volume is commonly lost through the evaporative lithium concentration process, and therefore, a significantly lower volume of brine is returned to the subsurface than was removed. Additionally, a RIB or injection well may not be connected to the subsurface horizon where the original brine was removed.

4.1.3 Surface Mining Checklist (Table A-3)

1. **Proximity to water table and dewatering –** Surface mining near or below the water table presents a high risk for the direct input of contaminants to the aquifer from open-pit mining and other land-disturbance activities. Dewatering alters groundwater levels and hydraulic gradients, which may impact baseflow in surface-water features. Dewatering usually requires constant operation and may present additional risks once pumping has ceased.
2. **Pit lake** – A pit lake may form in an open surface mine pit once dewatering ceases and groundwater levels rise and is a common source of contaminants (i.e., metals, metalloids) that can pollute surface water or groundwater depending on the nature of the lake (i.e., flow-through or terminal). A "Yes" response is warranted if the HCM or a groundwater flow model indicates that at least one pit lake is expected to form. Mining operations that backfill an open pit may prevent the formation of a pit lake, and therefore, a "No" response is appropriate.
3. **Hazardous geologic materials** – Extracted geologic materials that contain sulfide present a risk for AMD, whereas natural radioactive or contaminants of concern can introduce harmful constituents into surface water or groundwater above background or regulatory concentrations. The recommended ratio of acid neutralizing-potential to acid-production potential (NP:AP or NPR) should equal a range between 1.3 and 5, where less than 1 represents potentially acid generating material (Maest et al., 2005).
4. **Chemical additives** – The on-site storage and use of chemicals during processing pose risks to water quality if not managed, stored, used, and transported properly and in accordance with the Site Safety and Security Plan. Highly acidic compounds used to process ore may contaminate surface water and groundwater if contained on-site in tailings facilities. The presence and use of chemical additives can have direct and negative impacts on surface water in the event of a spill and may infiltrate into the subsurface and contaminate groundwater. Processed material must be neutralized prior to storage/disposal. If tailings have the potential for acid generation or could enable the migration of other harmful constituents, this should be marked as "Yes."
5. **Tailings facilities** – Tailings facilities constructed using methods other than the best available technology represent a substantial hazard to the natural environment because of the danger associated with tailings failure. Dry filtered tailings with drainage are currently the best available technology for surface-mining tailings per Morrill et al. (2022).
6. **Tailings fluids** – Tailings ponds or leachate drained from tailings are a potentially significant source of contaminants of concern to surface water or groundwater. Facilities must be zero discharge (i.e., all wastewater and leachate are captured and treated prior to reuse or release into the environment) to constitute a "No" response.

5.0 FRAMEWORK TO ASSESS HYDROLOGIC IMPACTS

The Framework to assess potential hydrologic impacts from lithium extraction in Nevada is provided in Appendix B. This section of the report complements the Framework because it provides descriptions and definitions of Framework concepts and additional context to identify areas of uncertainty and future work. Section headers and numbers used in this section are consistent with those presented in the Framework (Appendix B).

5.1 Pre-disturbance

5.1.1 Surface-water Hydrology

This section focuses on characterizing surface-water conditions and identifying potential impacts to surface water from lithium extraction of all resource types and all extraction methods. A surface-water survey should be conducted prior to any construction or land-disturbance activities associated with a lithium extraction facility. The purpose of the survey is to identify and characterize surface-water features (including seeps, springs, streams, rivers, lakes, ponds, and GDEs) within the HAI of a proposed or future lithium extraction facility.

1. To determine whether surface-water features have been adequately identified and characterized, a data review should be conducted, followed by a field survey for confirmation. The data review includes development of a database of surface-water locations and characteristics based on existing data (i.e., reports, aerial photography). All likely surface-water locations are then to be confirmed in the field. There are various protocols for creating surface-water inventories and characterization, such as the protocol for spring systems (Stevens et al., 2016). After field verification, surface waters should be selected for monitoring background conditions and long-term variability. Depending on the number and expanse of surface-water features identified, it may not be feasible to monitor all waters. Sites should be selected for monitoring that are representative of hydrologic, ecological, and hydrogeologic conditions, based on relative-risk sensitivity, and considering input from a range of experts depending on the project area, including hydrologists, hydrogeologists, geomorphologists, biologists, and sociocultural experts.
2. The location of the surface-water feature with respect to project boundaries, extraction activities, and the HAI should be considered. All surface-water features within the immediate project boundary should be considered for potential hydrologic impacts. Surface waters that are hydraulically connected to groundwaters, both up- and downgradient, in the project area should be considered (requires an HCM). Surface waters downstream/downgradient of the project area are subject to water-quality impacts from extraction operations (land disturbance, chemical spills, etc.).
3. The flow conditions and water sources of a surface-water feature are important considerations when identifying potential hydrologic impacts. Federal Register Vol. 85 No. 77 (US EPA, 2023) defines the following surface-water flow conditions for “Waters of the United States:”

    i) Perennial: flow that is continuous and year-round.

ii) Intermittent: flow that is continuous during certain times of the year and greater than flow in direct response to precipitation (e.g., seasonally when the groundwater table is elevated or when snowpack melts).

iii) Ephemeral: surface water flowing or pooling only in direct response to precipitation (e.g., rain or snow).

It is noted that the classification (perennial, intermittent, ephemeral) of a surface-water feature may change over time in response to shifts in climate conditions. For example, a drainage that has ephemeral flow during drought conditions may have intermittent flow in response to increased groundwater levels during wet periods.

A surface-water feature that has perennial flow is likely to receive inflow directly from groundwater. Intermittent flows may also receive groundwater inflows. Any lithium extraction operation that uses or impacts aquifers that are connected to surface-water features (meaning surface waters that gain water from groundwater and/or lose water to groundwater) may cause adverse impacts on those surface waters. Surface waters with ephemeral flow are unlikely to have any substantial groundwater input and would not be impacted by groundwater pumping directly. Independent of flow conditions or source water, all surface-water features near the project area may be at risk to water-quality degradation (i.e., sedimentation, chemical spills, etc.) and quantity change (i.e., increased or decreased runoff) from other facility activities (i.e., land disturbances).

Additional consideration should be given to springs where water is sourced from deep, regional aquifers and groundwater migrates through faults and fractures. The Basin and Range physiographic province is characterized by crustal thinning that has induced high geothermal-temperature gradients across the region, including Nevada. Thermally-heated springs are abundant across Nevada and are connected to deep, geothermal aquifers that may be targeted for geothermal energy and metal-rich brines (i.e., lithium). Like non-thermal springs, thermal-spring discharge areas often support GDEs, which in Nevada commonly host sensitive and endemic species. These ecosystems may be vulnerable to the cumulative hydrologic impacts associated with exploitation of fluids from geothermal resources. However, thermal springs from regional flow systems are less likely to be impacted by a project that is not pumping from deep reservoirs. Overall, the sensitivity of geothermal springs and the supported ecosystems is dependent on the project.

4. To determine whether a change in surface-water hydrologic conditions is associated with extraction activities, baseline conditions must be established by collecting site-specific data and compiling historical data. Baseline conditions account for natural variability over various timescales (i.e., short-term, seasonal, annual, and interannual) for varying climate conditions (i.e., average precipitation, wet years, drought years, etc.). The necessary baseline data may vary by site, but typically include surface-water flow, stage/level, temperature, chemistry (concentrations of metals, major ions, isotopes, etc.), and physical conditions (pH, suspended solids, dissolved solids, etc.). Biota and aquatic habitat should also be included in baseline monitoring programs. A qualitative assessment known as Proper Functioning Condition can be performed on the riparian area associated with stream reaches (US DOI, 2015) and springs/wetlands

(US DOI, 2020) that characterizes the physical interactions between hydrology, stabilizing vegetation, and geomorphology and can indicate impairments if repeat assessments are conducted over a sufficient timescale.

5. Groundwater supports a variety of ecosystems in Nevada that provide habitat for special-status species, including federally listed endangered and threatened species, many of which are endemic (Albano et al., 2021). Groundwater dependent ecosystems include wetland, riparian, and phreatophyte shrubland communities, many of which are associated with isolated springs that are not associated with active surface waters, like streams or rivers (Albano et al., 2021). The conservation of GDEs and special-status species near proposed and future lithium extraction facilities relies on the identification of these ecosystems and the development of adequate monitoring and mitigation plans to ensure natural hydrologic conditions are maintained throughout the life of the project.

5.1.2 Groundwater Hydrology

This section focuses on the characterization of the groundwater system and identifying potential impacts on groundwater associated with lithium extraction of all resource types and all extraction methods. All current and future lithium-extraction operations that plan to use or impact freshwater aquifers and/or brine aquifers, directly or indirectly, require the development of a comprehensive HCM to assess potential impacts on groundwater and surface water. There are three steps to building an HCM (details and definitions for these concepts are described throughout this section):

1) Defining hydrostratigraphic units (HSUs).
2) Establishing the groundwater budget.
3) Defining the flow system (Anderson et al., 2015).

1. Knowledge of the spatial variability of natural groundwater levels is necessary to calculate hydraulic gradients and define flow paths. This is critical for identifying future impacts on groundwater related to lithium extraction. It is also important to understand how the local groundwater trends fit into the regional groundwater system, especially when considering cumulative impacts of regional/basin-wide groundwater pumping. Defining the spatial variability of groundwater levels in areas where groundwater and surface water are connected is important, especially where GDEs are present, and needed to establish baseline conditions. If extraction activities alter the natural groundwater levels and flow paths, groundwater flow to GDEs may be impacted. Groundwater observation wells (or monitoring wells) are used to make in situ measurements of groundwater levels. Observation wells are sited based on knowledge of the local and regional hydrologic and hydrogeologic conditions and facility operations. Observation wells are key to providing the data necessary to understand the spatial variability of groundwater levels, the spatial extent of pressure-drawdown propagation from groundwater pumping, and surface-water/groundwater connectivity.

2. Groundwater conditions may vary over time in response to seasonal weather and long-term climate. The collection of temporal data of groundwater conditions is necessary for understanding the degree to which local groundwater levels and

groundwater quality change at different timescales. These data may be helpful to facility operators if a change in groundwater levels and quality is within the range of natural variation. Establishing baseline temporal conditions of groundwater levels and quality is particularly important where GDEs are present within the HAI. For example, it is important to know how spring flow to a wetland varies at seasonal and interannual scales under natural conditions. Then, thresholds can be established to identify impacts that may be attributed to extraction activities, climate, etc. If groundwater levels change in response to extraction activities, then spring flow and wetland conditions may be impacted. Several extraction activities can impact groundwater chemistry, including the reinjection of spent brines that have physical and chemical differences from the original brine. Groundwater pumping and injection can also impact the natural groundwater flow paths, modifying natural water-rock interactions and the geochemical conditions of the aquifer, which can alter groundwater chemistry (and spring discharge chemistry in the example above).

3. A groundwater budget should be prepared from a combination of field observations and literature values to summarize the magnitudes of groundwater inflows and outflows in the project area, in the HAI, or for the entirety of the hydrographic basin(s). Field-estimated inflows to an aquifer include groundwater recharge from precipitation and snowmelt, overland flow, or recharge from surface-water bodies, whereas outflows from an aquifer include spring flow, baseflow to streams, evapotranspiration, and pumping. Interbasin and interaquifer flow also occurs and may need to be considered. Lithium-extraction activities such as pumping and injection directly influence the groundwater budget. These changes to the groundwater budget should be quantified and placed into context of potential impacts on GDEs, and other water users and water-rights holders within the HAI and the impacted hydrographic basins. Additionally, land clearing for roads and facilities includes the removal of vegetation, which impacts evapotranspiration. Land disturbances can also modify surface soil conditions, and consequently overland flow and recharge rates. A series of reconnaissance studies of the groundwater resources of several hydrographic basins in Nevada were conducted in the 1960s (water.nv.gov/reconreports.aspx). The reconnaissance reports include groundwater budgets that can be used to inform the development of a refined and localized groundwater budget. It is noted that Nevada Reconnaissance Studies focus primarily on freshwater aquifers and do not always consider brine aquifers.

4. Aquifer hydraulic properties need to be determined to estimate the magnitude and timing at which pumping from an aquifer will impact the pumped aquifer, adjacent aquifers, and surface waters. Aquifers are partly defined using the concept of HSUs, which are geologic units of similar hydraulic properties. Site-specific data on geology/stratigraphy and aquifer hydraulic properties are required to define HSUs. Geologic information obtained from geologic maps, cross sections, well logs, and borings are combined with information on hydraulic properties, including hydraulic conductivity and storage from aquifer tests. These properties describe the rate at which water moves through an aquifer and the amounts of water the aquifer releases or takes into storage, respectively. Aquifer tests may include single-well or multi-well pumping tests and may be long-term (e.g., multiple days) constant discharge tests or

step tests (i.e., discharge varies over time). Slug tests may be performed to establish local hydraulic properties but should not be used to make inferences about aquifer conditions beyond the immediate vicinity of the tested well.

It is particularly important to know if the brine aquifer is confined, unconfined, or semiconfined. An unconfined aquifer is more likely to be connected to surface waters than a confined aquifer. Confined brine aquifers of finite lateral extent may have limited hydraulic connection to neighboring aquifers and surface water, which can reduce the impacts of pumping on these water resources. However, it may take an isolated brine aquifer a substantial amount of time to be replenished once pumping has ceased. Drilling into confined aquifers can produce artesian (i.e., free flowing) conditions due to groundwater pressure, which could result in an unintended release of brine at the surface. In the Amargosa basin, an exploratory borehole penetrated a confined aquifer and was unable to be plugged. An artesian "spring" formed at the abandoned borehole, known as Borehole Spring (Partner Engineering and Science, Inc., 2020). Additionally, surface-water features can be hydraulically connected to groundwater in confined aquifers, typically through faults and/or fractures. Groundwater pumping, borehole drilling, or reinjection of fluids into a confined aquifer can alter the hydraulic head, which could impact the flow rates of hydraulically connected surface-water features.

In summary, comprehensive aquifer characterization is critical to determining the magnitude and spatial extent of hydrologic impacts associated with any lithium facility that uses or impacts groundwater.

5.2 Land Disturbance and Infrastructure

With exception of lithium operations that can rely solely on existing infrastructure and facilities to extract and process lithium, all planned and future operations will include some degree of land disturbance associated with resource extraction or the installation/construction of new or modified infrastructure for both surface mining and brine operations. Disturbances may be associated with roads, power lines, buildings (e.g., processing facilities, offices, etc.), wells and well pads, open-pit/strip mines, waste-rock storage, processing/evaporation ponds, RIBs, mine tailings, surface-water diversions, canals, and culverts.

1. Characterize the location, type, function, and geometry of the land disturbance or facility. This will inform later questions that relate to surface-water and groundwater impacts. Are previously established facilities being used or repurposed, such as ongoing pumping of geothermal brines?
2. Erosion is a function of runoff velocity and volume induced by precipitation or facility operations, the surface permeability (which controls the infiltration rate), vegetative cover density and type, and the slope and distance of flow. Facility operations that disturb natural surfaces may include removing vegetative cover, decreasing the surface permeability (such as by paving a surface), and creating slopes at excavation or material piles, all of which increase erosion. A conservative FoS is 1.5 for slopes and a lower FoS presents greater risk. The recommended slope ratio measured by horizontal to vertical distance (H:V) is 5H:1V or better (e.g., 7H:1V) (Morrill et al., 2022). Eroded sediment entrained with runoff can begin on natural or

disturbed surfaces as sheet flow, and then concentrate in rills, drainages, and flood-control structures, which will increase the sediment load of surface water at or downstream of extraction sites. The deposition of sediment in streams or floodplains is known as sedimentation. A variety of ecological impacts are associated with erosion and sedimentation, including streambed habitat loss and alterations caused by braiding or high embeddedness. Erosion and sedimentation are major concerns at surface-mining sites because of the large amount of exposed rock, soil, and fine sediment and the relatively large footprint of operations.

Surface water may also be affected by facility infrastructure because of changes in flow rate, volume, or flow paths. Alterations refer to artificial conditions that affect the natural hydrologic system, often at the intersection of surface water and infrastructure. For example, road construction or flood-control structures may divert water that would otherwise flow into a stream, resulting in decreased streamflow. Increased runoff velocity because of land disturbance can cause flooding and channel scouring.

3. Consider the topography and geomorphology at the facility. A flat, low-lying area (such as a playa) will experience shallow, widespread flooding with low energy, which will deposit fine-grained sediment onto the land surface. An extraction site with bedrock outcrops or steep relief will experience high-energy flooding that will erode where runoff is concentrated. Facility operations commonly contain all types of areas that act as either erosional surfaces, transport reaches, or depositional environments. Best management practices (BMPs) for hydraulic structures should be designed in accordance with local, flood-control guidance, such as the *Hydrologic Criteria and Drainage Design Manual* (CCRFCD, 1999) for southern Nevada. The 100-year flood frequency event refers to a flood that has a 1% chance of being exceeded in any given year.
4. Groundwater well drilling and installation can introduce harmful constituents to groundwater during construction or because of vertical movement of water along or within the well. Relevant well-design factors include casing size, casing material, casing depth, screen size, screen material, screen depth, the filter pack material, the installation method, and the material used to seal the annular space (i.e., the area between the casing and borehole). Well materials may react with and impact groundwater geochemistry over time. For instance, polyvinyl chloride (PVC) is incompatible with organic compounds, whereas stainless steel and galvanized steel may experience corrosion by acids and bases (Fetter et al., 2017). The well head and annular space (generally up to 15 m [50 ft] below ground surface) should be sealed with a low-permeability material (e.g., cement) to prevent the vertical migration of water outside of the casing and packers should be used if the well is drilled through two or more hydrostratigraphic units to prevent groundwater mixing. Harmful chemicals may be released directly into groundwater or discharged onto the surface during drilling. Analyze the drilling methods, disposal plan, and mitigation. For further considerations pertaining to well drilling and installation see Chapter 8 of Fetter et al. (2017).

An additional consideration is if well rehabilitation is required at any point during the life of the facility. The goal of well rehabilitation is to clean/clear the well screen of any sediment or bacteriological buildup to reinforce hydraulic connectivity and flow between the well and the surrounding aquifer. Acids may be injected into a well to facilitate rehabilitation, which could impact the chemistry of the groundwater and any connected surface waters.

5. Describe the quantity, function, and geometry of ponds or RIBs. Disturbance associated with digging/excavating new ponds and RIBs can lead to erosion and increased sedimentation of nearby surface waters (see Section 5.2 #2). The footprint of RIBs may cover tens or hundreds of acres, which can impact surface-water runoff amounts and patterns in the watershed. Ensure the expected volume will be able to retain large magnitude precipitation events with adequate freeboard (i.e., the distance between the water-level surface and the embankment, generally 0.6 m [2.0 ft] is required). The capacity of a pond may be diminished over time because of sedimentation.
6. The hydrologic effects of waste rock and tailings may be physical, chemical, or both. For chemical effects, evaluate if liners are used and determine the distance between the bottom of the infrastructure and the water table. For physical effects, consider the design and construction of slopes. Steeper slopes result in higher-energy runoff with greater erosional potential. Slopes should be designed with a high FoS and consider BMPs for mitigation and monitoring (see Section 5.2 #2). Slope failure is concerning because of the sudden release of material leading to erosion and sedimentation, as well as the potential for the uncontrolled release of contaminants.

5.3 Extraction and Operations

This section details the potential hydrologic-based environmental impacts that may be incurred during i) groundwater pumping, which can be freshwater pumping or lithium-brine extraction (or both), and ii) surface mining of clays and hard rock. Extraction includes all processes used during the removal of the lithium resource (i.e., brine or ore) from the subsurface. Section 5.3.1 considers the infrastructure and operations associated with the use of pumping wells for extracting both lithium brine and freshwater. Freshwater extraction commonly occurs at all lithium operations, and therefore, Section 5.3.1 is relevant to freshwater extraction at brine, hard rock, and clay-mining operations. Surface water may be used as a freshwater source, but groundwater is more commonly used and is, therefore, the focus of this section. Additional information specific to surface mining is included in Section 5.3.2. Surface-mining extraction processes may include dewatering; excavation; storage of overburden, waste rock, and gangue; and the use of ponds or impoundments.

5.3.1 Lithium Brine and Freshwater Extraction

1. An evaluation of hydrologic impacts is performed based on historical groundwater and surface-water data, as well as the HCM. If there is high confidence in the hydrologic impacts evaluation, then the specific impacts identified should be addressed through the development and implementation of a mitigation plan. For example, if brine extraction is expected to alter the natural geochemical conditions of the targeted aquifer, steps should be taken to achieve pre-extraction geochemical

conditions to the extent possible. This is particularly important if the targeted aquifer is connected to adjacent aquifers or surface waters. Additional steps should be taken to ensure an adequate assessment has been or can be performed.

2. The development of an HCM is integral to the performance of the hydrologic impacts assessment. Section 5.1.2 provides additional details on steps for developing and using the HCM to assess surface-water and groundwater impacts associated with lithium extraction.

3. The design, placement, and usage of an extraction well(s) with respect to the local and regional surface waters and hydrogeology will contribute to the extent of the HAI. For example, a well used in surface mining to dewater a shallow unconfined aquifer that is hydraulically connected to a nearby stream may impact the streamflow. Conversely, a well that extracts brine from a deep confined aquifer on a seasonal basis may have less impact on surface waters than if the same well was to be pumped year-round.

4. The volume of freshwater or brine extracted per unit time (i.e., per pumping period, monthly, or annually) should be considered with respect to the groundwater budget for the local and regional groundwater system to anticipate short-term and long-term effects. If the volume of brine extracted each year accounts for a significant percentage of the annual inflows to the aquifer, then brine depletion may be expected in the reservoir. All groundwater extraction in the HAI, basin(s), and region should be considered to assess cumulative impacts and to evaluate effects by sector (i.e., mining, irrigation, municipal, etc.).

5. Pumping stresses the aquifer system in several ways and alters the natural groundwater conditions. Groundwater levels change in response to groundwater pumping, which impacts the groundwater flow system by rerouting flow paths. Changes in flow paths may alter water-rock interactions, which may cause changes in water quality. These changes may occur in both the pumped aquifer and hydraulically connected adjacent aquifers and surface waters. The extent that groundwater levels change in response to pumping depends on the hydraulic properties of the aquifer material (see Section 5.1.2). Under the same pumping conditions, a more permeable aquifer will have a flatter cone of depression that has less drawdown but impacts a larger area, and a less permeable aquifer will have greater drawdown over a smaller area. Unconsolidated aquifers consisting of sands and gravels are highly permeable, with hydraulic conductivity values that range from 10^{-5} to 1 m/s, whereas silts and clays are less permeable and have conductivity values of 10^{-12} to 10^{-5} m/s (Freeze and Cherry, 1979).

6. The extent and geometry of the pumped aquifer and the hydraulic conductivity of the aquifer and its boundaries control the degree of connectivity to adjacent aquifers. Pumping from an aquifer that is connected to a neighboring or overlying aquifer can lead to impacts on the natural groundwater conditions (quality and quantity/flow) of that aquifer. In the case of pumping effects transmitting into neighboring aquifers, the hydrologic area of influence extends beyond the pumped aquifer.

If a targeted aquifer is hydraulically isolated from adjacent aquifers, then the potential for impacts on unpumped aquifers is reduced. However, an aquifer that is disconnected receives little to no recharge from overlying or adjacent aquifers. Pumping from a disconnected aquifer may lead to water/brine depletion unless equal volumes of water are reinjected into the aquifer.

7. Surface waters that are connected to the impacted aquifers may be affected and should be monitored for quality and quantity/flow. Additional consideration should be given to surface waters that sustain GDEs, provide habitat for special status species, or provide water to livestock and other wildlife. To determine whether a change to hydrologic conditions of a surface-water feature can be attributed to freshwater pumping or lithium-brine extraction, baseline conditions need to be established prior to any activities (see Section 5.1.2).
8. Depending on aquifer physical and chemical characteristics, over pumping from an aquifer can lead to aquifer collapse (e.g., compaction, dissolution of evaporites or collapse of loosely consolidated sedimentary aquifers) and land subsidence.
9. Freshwater may be needed for a variety of purposes at a lithium extraction facility, including for use in the refining process, mixing with wastes/by-products, and for application to the land surface for dust suppression and desalination. Surface-mining operations may require freshwater for fire suppression. Freshwater may be extracted from groundwater or surface-water resources local to the project or transferred to the site. Water quality needs to be closely monitored, especially if the water is being applied to the land surface, to ensure no adverse impacts on surface waters and sensitive GDEs. Best management practices should be in place to prevent freshwater that is discharged to the land surface from pooling or flowing.

5.3.2 Surface Mine Resource Extraction

1. Characterize the type and amount of material to be excavated, including a geochemical characterization that is representative of all geologic media prior to mining. This should be thorough enough to capture potential geologic heterogeneities caused by stratigraphy, faults, igneous intrusions, or hydrothermal alteration. A geochemical analysis is required and will inform later questions that relate to surface-water and groundwater impacts.
2. Determine the mining methods for the given material types. Explosives may introduce harmful compounds directly to surface water or indirectly to groundwater via seepage. Determine the locations where overburden, lithium-bearing material, and waste rock will be stored.
3. Mining near, at, or below the water table enables a direct connection to the aquifer, which presents a high risk for contamination. Engineering controls and mitigation should be designed to prevent contaminants from releasing into the excavated area. This type of mining will require dewatering, either from the excavated area or using adjacent wells to form a cone of depression. Quantify the distance between the deepest mining operations and the water table. If mining occurs near the water table, it may be within the capillary fringe (i.e., the zone immediately above the water table where groundwater is present in pore space) and should be mitigated with dewatering.

Pumped groundwater may be naturally high in dissolved metals or other harmful constituents and varying levels of water treatment may be necessary prior to discharge into the environment or reuse for operations. Dewatering alters the groundwater hydraulic gradients, levels, and flow paths that may affect stream baseflows, springs and seeps, or GDEs. A monitoring plan should be implemented to provide early warning that groundwater drawdown could influence surface-water quantity.

4. Cut slopes (i.e., at an excavation edge) and fill slopes (i.e., at an engineered storage structure) must have appropriate controls to prevent mass movement. Cut slopes are often steep to reduce the volume of required excavation. Steeper slopes result in higher-energy runoff with greater erosional potential. Slope failure is a concern because of the sudden release of material leading to erosion and sedimentation, as well as the potential for the uncontrolled release of contaminants. A conservative FoS is 1.5 for slopes and the recommended slope ratio measured by horizontal to vertical distance (H:V) is 5H:1V or better (e.g., 7H:1V) (Morrill et al., 2022).

5. The presence of a pit lake can degrade water quality. A terminal pit lake is a pit lake that has no subsurface outflow, whereas a flow-through pit lake does have subsurface outflows to the aquifer. If the pit lake is a flow-through type, evaluate the potential for water-quality degradation in adjacent aquifers. This assessment includes the computation of water fluxes and prediction of filling rates. Water-budget estimations are integrated into geochemical models for water-quality predictions. See NDEP-BMRR (2021a) guidance for *Hydrogeologic Groundwater Flow Modeling at Mine Sites* and *Geochemical Modeling at Mine Sites* in Nevada (https://ndep.nv.gov/land/mining/regulation/guidance-policies-references-and-requirements). Additional considerations should be made regarding potential surface water-quality degradation in the case of overflow of a pit lake, where the pit-lake water level exceeds the pit-rim elevation.

6. Extraction and weathering of sulfide minerals can result in AMD. Conduct assessments of all materials that may generate acidic conditions, an assessment that may include geochemical modeling. Acid mine drainage can affect exposed rocks, including the pit wall, by interaction with oxygenated water. Waste rock with sulfide minerals requires engineering controls, acid neutralization, and treatment techniques. AMD can be an environmental concern because of the complexity and cost of remediation, the uncertainty involved in risk assessments, and the potential for surface-water and groundwater pollution and ecosystem degradation. See NDEP-BMRR guidance for acid-base accounting (NDEP-BMRR, 2019) and modeling for sulfide oxidation and reactive rock mass (NDEP-BMRR, 2021b). The NP:AP ratio should equal a range between 1.3 and 5, where less than 1 represents potentially acid-generating material (Maest et al., 2005).

7. Substances present in the excavated geologic media may be a source of dissolved chemical constituents. This includes trace concentrations of metals (e.g., aluminum, cadmium, chromium, copper, iron, lead, manganese, nickel, silver, mercury, and zinc), metalloids (e.g., arsenic), asbestos, selenium, and radioactive materials. The

risk of releasing chemical constituents will be a function of extraction type, mitigation and waste management practices, local climate, and the proximity to surface water and groundwater.

8. Stockpiles of overburden, waste rock, and gangue may generate acid and release other pollutants. Ensure materials have been representatively sampled for geochemical analysis and evaluate whether harmful constituents are present and will need to be mitigated. See NDEP-BMRR (2019).
9. The potential for water infiltration through waste-rock and overburden stockpiles should be evaluated and considered as a potential pathway for chemical constituents to impact surface and subsurface waters. If the underlying ground surface has moderate to high hydraulic conductivity, uncontrolled seepage into soil and groundwater is expected. If the storage pile is designed with a drain collection system, this fluid will be concentrated at discharge points that release into the environment. Water in a stockpile that moves laterally will discharge at toe seeps, the location of which will depend on topography. For all areas where infiltrated water may enter the hydrologic environment, evaluate the water-quality concerns, mitigation solutions, and monitoring procedures.
10. Ponds/impoundments may be used for a variety of purposes and can be ephemeral (e.g., a detention basin), perennial (e.g., long-term water storage for discharge from dewatering), or as a component of drainage (e.g., overburden/waste-rock storage) or seepage capture. The purpose and construction method are important to inform later questions on the potential hydrologic impacts. In addition, see Section 5.4.3 to evaluate a tailings pond. Evaluate if the pond is located in a valley and will have hydrodynamic containment (i.e., the water surface of the pond is below the elevation of groundwater in the flanking ridges). This type of natural containment induces an inward hydraulic gradient in which seepage will not propagate outward in all directions. Rather, seepage will only migrate downward in the valley, presenting less risk for widespread contamination. See Smith (2021) for more information on hydrodynamic containment.
11. Contaminants in ponds may result in the direct release of pollutants into the environment. Evaluate the monitoring and mitigation, including the response/remediation if a leak is detected. Evaluate controls in place to prevent overfilling and the release of water during a high-magnitude flood event. Consider the construction materials used in the structural zone of the embankment or dam. Earthen dams are susceptible to failure by erosion or seepage.
12. If impounded water is reused for facility operations, consider the pollution potential at its final application, such as on a dirt road for dust suppression. Treatment may be required if contaminants are present or if the final application is proximal to surface-water or groundwater resources.
13. See Section 5.4.1 for pond leakage and design considerations.
14. Material transportation may be accomplished by vehicles that require fuel or by pipelines. Tanks and pipes can have holes, joints, or damaged components that leak. Steel materials are subject to corrosion that may also cause leaks (Fetter, 1993).

Engineering controls should satisfactorily prevent and detect leaks. Evaluate system proximity to surface water, groundwater, and faults. Tanks or pipelines that are near or intersect faults in tectonically active areas increase the risk of a release.

5.4 Resource Processing

There are potential short-term and long-term hydrologic impacts associated with processes used to refine the lithium resource and produce the final lithium product. The use of chemical additives during brine and ore processing, and the by-products produced, may pose risks to water quality. The use of open-air evaporation ponds for brine processing can result in significant consumptive water use and impact the groundwater budget. Spent brines may be reinfiltrated into the subsurface, which can impact water quality and quantity.

5.4.1 Lithium Brine: Evaporative Concentration

1. Chemical additives are commonly used during the evaporative concentration process to precipitate compounds from the brine to assist the lithium concentration process. Acids and bases are also commonly used to adjust pH in evaporation ponds. Often, the compounds precipitated can be used beneficially (e.g., potash for processing and salts as an additional barrier to prevent infiltration of brines through pond floors/walls). If improperly stored or used, additives can be harmful to surface-water quality. If a spill occurs, additives may infiltrate the subsurface and impact groundwater quality.

2. Solid and liquid waste is commonly produced throughout the evaporative concentration process. The compounds that are precipitated at various stages of the evaporation process must be stored, treated, and transported carefully to avoid contaminating surface waters.

3. A critical factor considered during the design of an evaporation pond is how to minimize leakage from the pond into the subsurface. Ideally, ponds are constructed above low-permeability clay layers that prevent fluid infiltration into the subsurface. Plastic membrane liners are commonly used in addition to clay layers or in the absence of clays. Precipitated salts can also serve as added barriers. None of these methods are perfect and leakage is often inevitable. For example, plastic liners may contain punctures where fluid can flow through. Additionally, liners commonly need to be adhered together to cover the entire pond area and may be prone to leakage at these interfaces. Clay layers may not be laterally continuous, so leakage may pass through permeable lenses. Sensors and piezometers should be installed beneath ponds to detect leaks.

4. Additional processes may be used to augment the evaporative-concentration process, such as the use of alumina columns for selective adsorption of lithium. Any chemical or physical additives used in these processes should be carefully stored, transported, used, and discarded to prevent any direct or indirect contamination of surface waters.

5. The transfer of brine between evaporation ponds may be controlled by gravity, the use of dykes, pumping and conveyance through pipes, or other techniques. If brine is pumped between ponds, diesel generators may be used to power the pumps. Storage, transport, and usage BMPs for on-site fuels need to be considered to minimize the chances for surface-water contamination.

6. The use of RIBs poses a much greater risk to water quality if residual brine is added to shallow groundwater of superior quality. The use of RIBs should only be considered if there is a very deep unsaturated zone or if the local groundwater is of poor quality (e.g., playa aquifers commonly consist of groundwater with high dissolved solids and metals). An assessment of the shallow water quality is important for identifying potential degradation from the infiltration of high-salinity brines. Additionally, a geochemical characterization of the sediment beneath the RIBs and laboratory column experiments may be conducted to assess the potential for mobilizing chemical constituents (i.e., metals). Fate and transport models may be developed to assess impacts on the quality of shallow groundwater associated with RIBs and if any sensitive surface waters will be impacted. Observation wells should be installed to detect changes to water quality and validate models. Note that prolonged discharge can result in infiltration of fluids even to deep water tables (hundreds of feet below the surface), potentially impacting aquifers at depth.
7. Additional processing and refinement of the lithium-rich brines is required to produce the final lithium product. Processing either takes place at the extraction facility or may be transferred off-site. If the processing is conducted at an extraction facility, it should be known what additives (dry and wet chemicals, acids, bases, etc.) are stored on-site and how and when they will be used to minimize any impacts on water quality. For example, lime may be added to the brine to remove residual magnesium, sulfates, and borate ions, followed by the addition of soda ash to precipitate the calcium produced from the lime reactions. For boron removal, acids may be used to reduce the brine pH, as well as long-chain alcohol solvents.
8. Slurry and filtrate produced during the refining process may still contain substantial amounts of lithium after the initial round of refinement. If slurry or filtrate gets transferred back to the evaporation ponds for further processing, water-quality concerns associated with conveying/transporting these materials and using evaporation ponds should again be considered.
9. The amount of water expected to be lost to evaporation during the evaporative concentration process should be calculated/modeled before extraction activities commence. Many factors contribute to the amount of water that evaporates from the brine over time, such as pond dimensions, seasonal climatic/atmospheric conditions, salinity, and the expected starting and final lithium concentration of the brines. Atmospheric conditions that control evaporation rates include solar radiation, humidity, wind, and temperature. The amount of water evaporated may impact the volume that may then be returned to the subsurface unless the spent brines are mixed with other waters to create a volume that would maintain the groundwater budget. If steps are taken to reduce the amount of evaporation or to recapture evaporated water, the efficacy of these techniques should be documented and factored into the site groundwater budget. For example, at the Salar de Atacama in Chile, the brine is covered at the final pond to prevent further evaporation.
10. Leftover brine, freshwater, wastewater, and mixtures of these are commonly returned to the subsurface. To the degree possible, the aquifers in which the fluid came from should be replenished to their pre-extraction levels. In practice, it may prove difficult to replenish each of the impacted aquifers and return to pre-extraction levels. As

previously stated, the infiltration of water through RIBs leads to localized groundwater mounding that may temporarily alter groundwater flow paths and baseflow to connected surface waters. Additionally, the RIB may not be connected to the subsurface horizon where the original brine was removed.

11. Freshwater may be needed during lithium processing. Freshwater may be sourced from local aquifers or surface waters or transferred to the site (i.e., from outside the HAI; if from a different basin, this is known as interbasin transfer). If freshwater comes from aquifers local to the project area, the magnitude of impacts on groundwater levels and connected surface-water baseflows is dependent on the volume of freshwater required and aquifer hydraulic properties. If surface-water resources are used to meet freshwater requirements, the extent of impacts on targeted and connected surface waters depends on the volume extracted and proximity to sensitive habitats and ecosystems.

5.4.2 Lithium Brine: Direct Lithium Extraction

1. Once the lithium-rich brine has been extracted from the aquifer, processing and refinement via DLE techniques can be used to produce the final lithium product. Direct lithium extraction either takes place at the extraction facility or brine may be transferred for off-site processing. If transferred off-site, careful consideration should be given to the BMPs in place to minimize potential impacts on water quality during transport/conveyance of the brine. There are several concerns regarding potential impacts on water quality if DLE is conducted on-site (continue to the sections below).
2. There are a variety of DLE techniques, each with the potential to impact hydrology. Many DLE techniques are proprietary and methodologies vary by site. Therefore, detailed protocols and steps may be unavailable. However, information that should be disclosed and considered for their potential hydrologic and greater environmental impacts include any additives to be used, the quantity/volume to be used, and the stage of application. Chemical additives have the potential to impact water quality if not handled properly.
3. As stated previously, spent brines and water are typically returned to the subsurface via injection wells or RIBs. The primary goal of reinjection should be to return impacted aquifers (pumped and unpumped) to their natural, pre-pumping physical and chemical conditions. However, there are water-quality concerns associated with reintroducing spent brines into the subsurface. In general, if the injected/infiltrated brine has physical and chemical characteristics that are different from the fluid in the aquifer being recharged, the water quality in the recharged aquifer will be altered. If fluid originally from a deeper brine aquifer is infiltrated to a shallow freshwater aquifer, it poses a high potential hazard. The degree to which the quality changes varies depending on the geochemical conditions of the aquifer, the chemical and physical properties of the brine, and the volume of brine (in the aquifer and in the injected/infiltrated fluid). It is noted that the quality of a lithium-brine reservoir renders it not suitable as a water resource and that the quality degradation may be of greatest concern to a lithium producer in terms of long-term resource viability from dilution of the lithium resource.

4. Spent brines are returned to the subsurface, which will contribute to the overall groundwater budget. In theory, if the volume of brine injected into the aquifer equals the volume pumped, then the groundwater budget is returned to equilibrium. However, the period that it takes to reach equilibrium depends on the hydrogeologic conditions of the impacted aquifers. The pumping and reinjection stresses on an aquifer may impact levels for an amount of time that can have lasting effects to adjacent aquifers or connected surface waters. If lithium-enriched brines were originally pumped from two or more aquifers, replenishing all impacted aquifers may become increasingly complex. If the original production interval is deep and/or isolated, it may not be considered as part of the overall groundwater budget. For example, the reconnaissance reports introduced earlier (water.nv.gov/reconreports.aspx) primarily focus on aquifers that are possible water resources and put little or no emphasis on brines. Maintaining the volume of an isolated brine aquifer is of little concern for hydrologic impacts unless it affects the hydrology of other high-quality units. The use of reinjection wells and RIBs introduces high volumes of water into the subsurface, which can produce groundwater mounds that impact groundwater flow paths. Depending on the hydraulic properties of the injected aquifer and its connection to adjacent aquifers, this may impact flow exchange rates. If the return aquifer is connected to surface waters, there could be impacts on the flow or stage of the surface waters. Additional considerations should be made if local surface waters support GDEs or other ecosystems.

5.4.3 Surface Mine Resource Processing

1. Inventory the chemicals used in the processing steps, including the separation, roasting, acid leaching, precipitation/purification, and/or conversion procedures. See the EPA *Toxic and Priority Pollutants Under the Clean Water Act* to identify contaminants of concern (https://www.epa.gov/eg/toxic-and-priority-pollutants-under-clean-water-act#toxic).

2. Hydrologic contaminants are either solutes (i.e., dissolved into water) or non-aqueous liquids (i.e., non-dissolved). Several factors influence how a substance may mobilize into the environment, and these can be quantified by a substance's specific gravity, polarity, and range of solubility in water. Substances with high specific gravity are denser than water and will migrate deeper into the subsurface, whereas low specific gravity substances are lighter than water and will overlie it. Polar substances are typically more water-soluble than non-polar substances that repel the polar water molecule. Solutes may be removed from solution by sorption in which solutes adsorb onto the surface of soil or sediment. Contaminants that are soluble in groundwater are concerning if they have complex chemical structures or are present in high concentrations. Contaminants that are denser than water are extremely challenging to remediate because contaminated zones can be difficult to access and treat.

   Chemical transformation can change a substance's structure, concentration, or mechanism for transport. Inorganic substances may undergo redox reactions when a change in the oxidation state transforms the substance into a more or less hazardous form. Biological processes can transform organic chemicals into less hazardous forms or entirely break down compounds. The topics provided here are a few basic concepts of contaminant hydrogeology (see Fetter et al. [2017] for greater detail).

3. Chemical storage and transportation may be accomplished by tanks and pipelines, respectively. As mentioned in Section 5.3.2, tanks and pipes may leak at holes, joints, or damaged components at the tank/pipe and associated plumbing. Steel materials are subject to corrosion that causes leaks (Fetter, 1993). Engineering controls should satisfactorily prevent and detect leaks. Evaluate the system's proximity to surface water, groundwater, and faults. Tanks or pipelines that are located near or intersect active faults in a tectonically active area have increased risks of unexpected release.

4. Acidic compounds used during processing can result in AMD if processed materials containing acid are stored on the surface or underground. Tailings with acidic compounds or sulfide minerals require engineering controls, acid neutralization, and treatment techniques. See Section 5.3.2 for AMD assessment considerations and guidance.

5. Processing waste is usually a small proportion of the total waste by volume relative to extracted waste rock and overburden. However, processing waste may be mixed with waste from extraction, and therefore, contaminated processing waste could be uncontained in a larger waste stream. Determine the waste-management solution for mixed waste streams and evaluate the hazards for solid and liquid wastes.

6. Tailings can include sediment, water, blasting chemicals, separation chemicals, metals, or other mineral constituents. Tailings are a primary source of dissolved pollutants (e.g., metals, salts, nitrates, etc.) that can be released into the hydrologic environment abruptly (i.e., in a structural failure) or chronically over time (i.e., seepage to surface water or groundwater). See Section 5.4.3 to evaluate a tailings pond or ponded liquid waste, respectively.

   Filtered tailings that are thickened and then filtered by vacuum or positive pressure are considered the best available technology to reduce the risk of structural failure (Morill et al., 2022). Additionally, the Independent Expert Engineering Investigation and Review Panel (IEEIRP, 2015) recommends that the best available technology includes filtered tailings that eliminate surface water and promote unsaturated material using drainage and compact deposits. Contaminant leaching potential tests should be conducted for tailings to compare leached fluid with baseline water quality and regulatory water-quality standards. The potential for adverse water-quality effects is considered high if contaminant concentrations exceed standards by more than 10 times (INAP, 2009).

7. Treatment of tailings and other solid waste may include filtering/dewatering, acid neutralization, or other chemical measures to reduce adverse environmental effects. Drying tailings prior to deposition decreases pore water to provide greater structural stability and less hydraulic connection throughout the tailings facility. If acidic compounds will be deposited in the tailings, the material should be evaluated for its NP:AP ratio. See Section 5.3.2 for AMD assessment considerations and guidance.

8. Measures should be used to prevent water from entering tailings facilities, such as hydraulic structures to prevent flooding or runoff and surface covers to prevent precipitation from infiltrating. Groundwater infiltration mitigation should include impermeable liners that underlie the tailings facility with drainage systems to transport water out of tailings. Drained water at the outlet must not be discharged directly into a surface-water body. Ideally, facilities are zero discharge where all wastewater and leachate are collected and treated prior to reuse or release into the environment.
9. Backfilling tailings into excavation areas can reduce the amount of aboveground tailings material and reduce the risk of structural failure (Morrill et al., 2022). However, backfilling poses a greater risk to groundwater quality, especially if a shallow aquifer is near the backfilled area. Special consideration should be given to the underlying geology. Faults or fractured rock may provide preferential flow paths where dissolved contaminant velocity is greater and flow paths may be more complicated.
10. Tailings may instead be mixed with water into a slurry and impounded in tailings ponds. This is the conventional method of mine tailings storage/disposal. Tailings ponds or subaqueous tailings (i.e., when water is used to cover tailings for AMD prevention) are not recommended (Morrill et al., 2022). Tailings ponds present an acute hazard to wildlife and a potentially significant source of pollutants and contaminants of concern (US EPA, 1997). Tailings that are constructed using an upstream sequentially raised tailings dam (i.e., where the dam wall is created by placing successive layers of tailings on top of each other) are especially prone to failure and must not be implemented (Morrill et al., 2022).
11. Liquid waste from processing may also include ponded water that is drained from dry stack tailings or at seepage collection ponds. Ponds should be zero-discharge facilities. Tailings ponds that are in hydraulic connection with groundwater experience the highest rates of seepage, and therefore, the greatest solute load (i.e., the mass of a solute that enters a water body over time) (Smith, 2021). See Section 5.4.1 for pond leakage and design considerations.
12. Surface-water resources and any associated ecosystems may be severely degraded if contaminant seepage occurs into groundwater or if they are located downstream of a tailings failure. Failure scenario modeling should include the worst-case scenario in which all tailings at a fully built facility are mobilized.
13. Numerical environmental geochemistry models can be used to predict contaminant fate and transport and identify areas where contaminants are expected to interact with the environment. A management plan should include the monitoring procedures and thresholds needed to identify risks before they occur, as well as the corresponding mitigation steps. The management plan should make predictions about contaminant transport scenarios with minimal uncertainty that can be verified by in situ data collection and be adaptable to dynamic conditions.

5.5 Closure of a Lithium Extraction Facility

The permanent closure of a lithium extraction facility includes reclamation and restoration activities to achieve long-term hydrologic stability and return the impacted area to its natural, pre-extraction environmental conditions to the degree possible. Facility closure aims to achieve long-term chemical and physical stabilization of the site and other affected areas, but this is not always feasible. Facility-closure activities should consider the entire hydrologic area of influence. The procedures, methods, and timeline for detoxification and stabilization of all known and potential contaminants may themselves cause hydrologic impacts. Facility-closure activities that may lead to hydrologic impacts include land restoration and stabilization, regrading and revegetation, removal of facilities (e.g., processing, fueling, etc.), reclamation and covering of open-pit or strip mines, waste-rock or tailings stockpiles, regrading or backfilling ponds and RIBs, and well abandonment.

1. Evaluate the methods used to return the surface to its original environmental conditions. Land disturbance associated with earthmoving, facility deconstruction, and demobilization (e.g., disconnection and removal of facilities, equipment, etc.) activities may affect local surface water and groundwater similar to Section 5.2, but it is necessary to return the environment to its natural, pre-extraction state. These potential effects are minor compared to the greater long-term risks posed to surface-water resources if the surface is not restored to pre-extraction conditions.
2. Evaluate the methods used to return the subsurface to its original environmental conditions. The hydraulic characteristics of geologic materials that are removed then backfilled will likely change because of alterations to the structure (e.g., consolidated bedrock than has been blasted), stratigraphy (i.e., layering of rock/soil/sediment), bulk density (i.e., amount of compaction), and moisture content. Homogenized and highly disturbed material will typically possess greater hydraulic conductivity and promote greater infiltration rates. Water-quality effects from past activities may not be observed for hundreds of years after closure because of long groundwater residence times (i.e., travel times). For surface mines, dewatering and pit-lake water management often stop once operations are complete, leading to groundwater accumulating in excavated areas as groundwater levels rebound, which may present concerns for water/rock geochemical interactions, particularly the increased potential for AMD or leaching constituents into groundwater.

5.6 Post-closure of a Lithium Extraction Facility

A post-closure monitoring program (spanning years to decades) provides data to confirm whether chemical and physical stabilization has been achieved, and the degree and timing of any delayed effects to groundwater or surface water.

1. Long-term hydrologic data collection is required to identify impacts on surface water and groundwater. Delayed impacts on groundwater and surface water can occur because of the hydrogeologic characteristics of an area. Aquifers of low hydraulic conductivity and/or no-flow boundary conditions (aquifer boundaries with no recharge) can result in delayed or limited groundwater level recovery. This effect may be observed in pumped aquifers, connected neighboring aquifers, and connected surface waters and may impact water quantity and quality. Monitoring should include

water quality and levels for surface water and groundwater at appropriate intervals to capture seasonal climate cycles and extreme events. Thresholds should be established for all water quality and quantity parameters that would trigger a mitigation action.

2. Slope failure may result in erosion and sedimentation impacting nearby surface water and, in the case of a tailings failure, catastrophic release of potentially contaminated material into the environment. Slope-stability monitoring is enhanced when coupled with groundwater monitoring to observe seepage within slopes. Cut slopes and fill slopes must have appropriate controls to prevent mass movement. For surface-mining tailings, Morrill et al. (2022) recommends that tailings facilities are monitored, inspected, maintained, and reviewed until no possible mechanism for failure exists because of the consequences of tailings failure. Furthermore, Morrill et al. (2022) recommends that tailings be designed to withstand extreme natural events, including the probable maximum flood (i.e., the most severe flood that is reasonably possible, likely greater than the 10,000-year recurrence interval) and the maximum credible earthquake (i.e., the largest magnitude earthquake that could occur in a source area, possibly as rare as the 100,000-year recurrence interval).

3. The fate and transport of dissolved chemical constituents can be complicated in many hydrologic and hydrogeologic settings. A major control on groundwater chemistry is the duration of the interaction between water and materials or constituents. Long-term environmental geochemistry, therefore, strongly depends on the presence of water, the degree of disturbance, and the underlying geology. Geochemical conditions may change over time that increase the risk of environmental effects, such as an increasingly oxidizing environment. Numerical environmental geochemistry models should be used to forecast contaminant fate and transport, and identify areas where contaminants are expected to interact with the environment to assess a sufficiently long period following closure. A management plan should include monitoring procedures and early-warning thresholds to identify significant changes to hydrologic parameters before they occur, and separate thresholds that would trigger mitigation. The management plan should be able to make predictions about contaminant transport scenarios with minimal uncertainty that can be verified by in situ data collection and be adaptable to dynamic conditions.

6.0 SUMMARY

The extraction and processing of lithium to meet renewable energy demands are strongly linked to surface-water and groundwater hydrology near proposed lithium surface mining or brine withdrawal projects in Nevada. This study identifies the breadth and connectivity of potential adverse effects from lithium extraction projects to the quantity and quality of local water resources. The document provided here is not an exhaustive list of all possible hydrologic impacts, but they enable users evaluating future lithium projects to consider critical threats, especially alterations to natural conditions that may affect the vitality of water bodies and ecosystems. The Hydrologic Risk Assessment Checklist was developed to characterize the risks of lithium projects using a standardized set of questions and highlight the areas that pose the greatest concerns for local hydrology. The accompanying Framework to Assess Hydrologic Impacts guides users through the environmental, operational, and monitoring/mitigation conditions that may influence or degrade water resources.

Potential water-quality and -quantity concerns identified here depend, in part, on the resource type, extraction and processing techniques, and environmental conditions. Lithium-brine operations commonly result in high water-volume losses from the use of evaporitic techniques. Direct lithium extraction techniques may also lead to high water consumption; however, there are presently no DLE systems operating at production scale. The reinjection of brines to the subsurface has the potential to impact the quantity and quality of groundwater and connected surface waters. Surface-mining operations may impact water quality by disturbing geologic materials and altering natural geochemical conditions. Surface-mining operations that employ dewatering have increased potential for degrading water quality, especially as groundwater levels rebound once dewatering has ceased. The extent of hydrologic risk depends on the proximity of a lithium extraction facility and degree of hydraulic connection to fresh surface-water and groundwater resources.

7.0 REFERENCES

Albano, C.M., B.A. Minor, C.G. Morton, and J.L. Huntington, 2021. Baseline Assessment of Groundwater Dependent Vegetation in Relation to Climate and Groundwater Levels in Select Hydrographic Basins of Nevada. Desert Research Institute Publication No. 41283.

Anderson, M.P., W.W. Woessner, and R.J. Hunt, 2015. Applied Groundwater Modeling: Simulation of Flow and Advective Transport. Academic Press, pp. 564.

Bradley, D.C., L.L. Stillings, B.W. Jaskula, L. Munk, and A.D. McCauley, 2017. Critical Mineral Resources of the United States—Economic and environmental geology and prospects for future supply, Chapter K: Lithium. Eds K.J. Schulz, J.H. DeYoung, Jr., R.R. Seal, II, and D.C. Bradley. U.S. Geological Survey Professional Paper (1802), pp. K1-K21, https://doi.org/10.3133/pp1802K.

Brown, T., A. Walters, N. Iodine, G. Gunn, R. Shaw, and D. Rayner, 2016. Mineral Profile: Lithium. *Commodity Profiles*, pp. 1-39.

Clark County Regional Flood Control District (CCRFCD), 1999. Hydrologic Criteria and Drainage Design Manual. Las Vegas, NV.

Fetter, C.W., 1993. *Contaminant Hydrogeology*. Macmillan Publishing Company, New York.

Fetter, C.W., T. Boving, and D. Kreamer, 2017. *Contaminant Hydrogeology*, Third edition. Ed. Waveland Press, Long Grove, Illinois.

Flexer, V., C.F. Baspineiro, and C.I. Galli, 2018. Lithium Recovery from Brines: A vital raw material for green energies with a potential environmental impact in its mining and processing. *Science of the Total Environment* (639), pp. 1188-1204.

Freeze, R.A., and J.A. Cherry, 1979. *Groundwater*. Prentice-Hall Inc., Englewood Cliffs, Vol. 7632, p. 604.

Garrett, D.E., 2004. *Handbook of Lithium and Natural Calcium Chloride: Their deposits, processing, uses, and properties.* Academic Press, Amsterdam, The Netherlands.

Independent Expert Engineering Investigation and Review Panel (IEEIRP), 2015. Report on Mount Polley Tailings Storage Facility Breach. Province of British Columbia, p. 124.

International Network for Acid Prevention (INAP), 2009. Global Acid Rock Drainage Guide (GARD Guide).

Kaunda, R.B., 2020. Potential Environmental Impacts of Lithium Mining. *Journal of Energy & Natural Resources Law* (38:3), pp. 237-244, DOI:10.1080/02646811.2020.1754596.

Lithium Americas Corp., 2022. Feasibility Study, National Instrument 43-101 Technical Report for the Thacker Pass Project, Humboldt County, Nevada, USA, https://minedocs.com/19/Thacker-Pass-FS-11022022.pdf

Maest, A.S., J.R. Kuipers, C.L. Travers, and D.A. Atkins, 2005. *Predicting Water Quality at Hardrock Mines: Methods and Models, Uncertainties, and State-of-the-Art*. Earthworks, Washington, DC.

McKenna, S., Hoekman, S.K., Lutz, A. D., Gentilcore, D. M., 2022. Lithium Opportunities and Challenges in Nevada, Desert Research Institute: Reno, NV, DRI Publication Number 41290

Meshram, P., B.D. Pandey, and T.R. Mankhand, 2014. Extraction of Lithium from Primary and Secondary Sources by Pre-treatment, Leaching, and Separation: A comprehensive review. *Hydrometallurgy* (150), ISSN 0304-386X, https://doi.org/10.1016/j.hydromet.2014.10.012.

Morrill, J., D. Chambers, S. Emerman, R. Harkinson, J. Kneen, U. Lapointe, A. Maest, B. Milanez, P. Personius, P. Sampat, and R. Turgeon, 2022. *Safety First: Guidelines for Responsible Mine Tailings Management*. Earthworks, MiningWatch Canada and London Mining Network.

Munk, L.A., S.A. Hynek, D.C. Bradley, D.F. Boutt, K. Labay, and H. Jochens, 2016. Lithium Brines: A global perspective. *Reviews in Economic Geology* (18), pp. 339-365.

Nevada Administrative Code (NAC), 2022. Chapter 445A Water Controls, Part 433, Minimum Design Criteria: Universal requirements; minimum criteria for permanent closure if plan not approved by Department before September 1, 2018; areas where groundwater is near surface; proximity of new process components to dwellings; liability for degradation of water. Revised May 2022.

Nevada Division of Environmental Protection – Bureau of Mining Regulation and Reclamation (NDEP-BMRR), 2019. Waste Rock, Overburden, and Ore Evaluation. Nevada Division of Environmental Protection – Bureau of Mining Regulation and Reclamation, March 22, 2019.

NDEP-BMRR, 2021a. Guidance for Hydrogeologic Groundwater Flow Modeling at Mine Sites. https://ndep.nv.gov/uploads/land-mining-regs-guidance-docs/20210420_Hydro_GuidanceRev00_ADA_1.pdf (accessed April 21, 2023).

NDEP-BMRR, 2021b. Guidance for Geochemical Modeling at Mine Sites. Nevada Division of Environmental Protection – Bureau of Mining Regulation and Reclamation, May 11, 2021, https://ndep.nv.gov/uploads/land-mining-regs-guidance-docs/20210521LK_GuidnceDoc_GeoChem_Mod_Fillable.pdf

Nevada Division of Minerals (NDOM), 2023. Nevada Division of Minerals Open Data Site. Available at: https://data-ndom.opendata.arcgis.com/pages/ndomdatagallery

Parker, S.S., B.S. Franklin, A. Williams, B.S. Cohen, M.J. Clifford, and M.M. Rohde, 2022. Potential Lithium Extraction in the United States: Environmental, Economic, and Policy Implications.

Partner Engineering and Science, Inc., 2020. 2020 Amargosa Basin State of the Basin Report: Amargosa River Basin Inyo and San Bernardino Counties, California. Partner Project Number SM16-176930, prepared for The Amargosa Conservancy, https://www.amargosaconservancy.org/wp-content/uploads/2022/03/2020-Amargosa-State-of-the-Basin-Report-Zdon-compressed.pdf.

Rytuba, J.J., and R.K. Glanzman, 1979. Relation of Mercury, Uranium, and Lithium to the McDermitt Caldera Complex, Nevada-Oregon. Nevada Bureau of Mines and Geology, Papers on Mineral Deposits of Western North America, Report 33, pp. 109-117. (Also available at http://pubs.er.usgs.gov/publication/70043142.)

Saito, L., S. Byer, K. Badik, K. McGwire, L. Provencher, and B. Minor, 2020. Mapping Indicators of Groundwater Dependent Ecosystems in Nevada: Important resources for a water-limited state. *Journal of the Nevada Water Resources Association*, Winter 2020:48-72. DOI: 10.22542/jnwra/2020/1/3.

Simmons, S., Kirby, S., Verplanck, P., Kelley, K, 2018. Strategic and critical elements in produced geothermal fluids from Nevada and Utah. In Proceedings of the 43rd Workshop on Geothermal Reservoir Engineering, Stanford, CA, USA, 12–14; Stanford University: Stanford, CA, USA.

Stantec, 2021. Clayton Valley Lithium Pilot Plan Project: Mining Plan of Operations and Nevada State Reclamation Permit Application. BLM File Serial Number: NVN-99670; NDEP File Number: NEV-0412. Prepared for Schlumberger Technology Corporation.

Smith, L., 2021. Hydrogeology and Mineral Resource Development. The Groundwater Project, Guelph, Ontario, Canada.

Stevens, L.E., A.E. Springer, and J.D. Ledbetter, 2016. Springs Ecosystem Inventory Protocols. Springs Stewardship Institute, Museum of Northern Arizona, Flagstaff, AZ.

Stringfellow, W.T., Dobson, P.F, 2021. Technology for the Recovery of Lithium from Geothermal Brines. *Energies*, 14, 6805. https://doi.org/10.3390/en14206805

U.S. Bureau of Land Management (US BLM), 2020. Thacker Pass Lithium Mine Project: Final Environmental Impact Statement. BLM Winnemucca District, Humboldt River Field Office, NV, December 4, 2020. DOI-BLM-NV-W010-2020-0012-EIS.

US BLM Tonopah Field Office, Nevada, 2021. Environmental Assessment for Clayton Valley Lithium Pilot Plant Project. DOI-BLM-NV-B020-2021-0015-EA, https://eplanning.blm.gov/eplanning-ui/project/2011353/570.

US BLM Tonopah Field Office, Nevada, 2021a. Environmental Assessment for Clayton Valley Lithium Pilot Plant Project. Supplemental Environmental Report – Surface and Groundwater Resources, DOI-BLM-NV-B020-2021-0015-EA, NVN-99670, https://eplanning.blm.gov/eplanning-ui/project/2011353/570.

U.S. Department of the Interior (US DOI), 2015. Riparian Area Management: Proper functioning condition assessment for lotic areas. Technical Reference 1737-15. Bureau of Land Management, National Operations Center, Denver, CO.

US DOI, 2020. Riparian Area Management: Proper functioning condition assessment for lentic areas. 3rd ed. Technical Reference 1737-16. Bureau of Land Management, National Operations Center, Denver, CO.

U.S. Environmental Protection Agency (US EPA), 1997. EPA's National Hardrock Mining Framework. EPA Office of Water (4203), https://www.epa.gov/sites/default/files/2015-10/documents/hardrock_mining_framework_0.pdf

US EPA, 2023. Revised Definition of Waters of the United States. Federal Register, Vol. 88, No. 11, pp. 3004-3144.

U.S. Geological Survey (USGS), 2018. Saline Water and Salinity, https://www.usgs.gov/special-topics/water-science-school/science/saline-water-and-salinity#:~:text=Fresh%20water%20-%20Less%20than%201%2C000%20ppm%20Slightly,ocean%20water%20contains%20about%2035%2C000%20ppm%20of%20salt.

Vera, M.L., W.R. Torres, C.I. Galli, A. Chagnes, and V. Flexer, 2023. Environmental Impact of Direct Lithium Extraction from Brines. *Nature Reviews Earth and Environment* (4), pp. 149-165. https://doi.org/10.1038/s43017-022-00387-5.

Wanger, T.C., 2011. The Lithium Future – Resources, Recycling, and the Environment. *Conservation Letters* (4:3), p. 202.

THIS PAGE LEFT INTENTIONALLY BLANK

APPENDIX A. HYDROLOGIC RISK ASSESSMENT CHECKLIST

The Checklist is a series of questions that require Yes/No responses, with **a "Yes" response indicating greater hydrologic risk than a "No" response**. Generally, the potential for hydrologic risk increases with the total number of "Yes" responses for the project under evaluation. The Checklist provides a space for notes to allow the user to capture nuances, complications, or observed factors that may supplement the "Yes" or "No" response. If the answer to a question is unknown because of a lack of site characterization or there is high uncertainty, it should be marked as a "Yes" to represent risk. Further investigations (e.g., data collection, testing, etc.) should be conducted to reduce uncertainty.

Neither the Checklist nor Framework should be used as a comprehensive review that covers all environmental risks, or as an alternative to intensive, site-specific hydrologic impact assessments that precede regulatory approval. Instead, the Checklist and Framework may be used to identify areas of uncertainty related to the potential for hydrologic impacts associated with lithium extraction. After applying these tools, more detailed site-specific analyses should be considered and implemented to address the areas of uncertainty. The Checklist and Framework may be paired with other assessments to identify areas or waters of concern (e.g., pairing with an ecological assessment to identify aquatic habitat that may be at risk).

Table A-1: General Hydrology Checklist

This table applies to the resource types and extraction methods listed below.

Resource Types	Extraction Methods
Brine	Evaporative concentration
Clay	Direct lithium extraction
Hard rock	Surface strip mining
	Surface pit mining

#	Yes	No	Risk Assessment Question
1.	¨	¨	Are there perennial or intermittent springs or seeps in the hydrologic area of influence (HAI)? Notes:
2.	¨	¨	Do springs or seeps in the HAI contain geothermally heated waters? Notes:
3.	¨	¨	Are springs or seeps in the HAI downgradient of site facilities? Notes:
4.	¨	¨	Are there perennial or intermittent streams, rivers, lakes, or ponds in the HAI? Notes:
5.	¨	¨	Are there streams, rivers, lakes, or ponds in the HAI that are downgradient of site facilities? Notes:
6.	¨	¨	Are there any groundwater dependent ecosystems (i.e., springs, wetlands, riparian zones) in the HAI? Notes:
7.	¨	¨	Does the proposed/permitted project area have a relatively large (>5,000 acres) total footprint? Notes:
8.	¨	¨	Is there a high potential for erosion and sedimentation, such as excavated slopes, earthen stockpiles, or facilities constructed within the floodplain? Notes:
9.	¨	¨	Will groundwater pumping (e.g., during exploration and aquifer characterization activities, brine extraction, dewatering, or for freshwater operations) affect the water supply of surface-water features in the HAI? Notes:
10.	¨	¨	Are shallow freshwater aquifers (water table within 100 ft of land surface) present below any extraction facilities on the land surface? Notes:

Table A-2: Lithium Brine Checklist

This table applies to the resource types and extraction methods listed below.

Resource Types	**Extraction Methods**
Brine	Evaporative concentration Direct lithium extraction

#	Yes	No	Risk Assessment Question
1.	¨	¨	Is groundwater/brine extracted from aquifers that are hydraulically connected to any adjacent aquifers? Notes:
2.	¨	¨	Will additives be used at any point during brine processing at an on-site facility (i.e., chemicals, acids, bases, etc.) Notes:
3.	¨	¨	Are evaporation ponds or storage ponds used at any point during processing? Notes:
4.	¨	¨	Is there potential for brine extraction to lead to aquifer collapse and/or land subsidence? Notes:
5.	¨	¨	Are any solid wastes or by-products produced during brine processing at an on-site facility? Notes:
6.	¨	¨	Are rapid infiltration basins used to return water/brine to the subsurface? Notes:
7.	¨	¨	Is the volume of fluid extracted from the subsurface greater than volume returned to the subsurface? Notes:

Table A-3: Surface Mine Checklist

This table applies to the resource types and extraction methods listed below.

Resource Types
Clay
Hard rock

Extraction Methods
Surface strip mining
Surface pit mining

#	Yes	No	Risk Assessment Question
1.	¨	¨	Will the surface mine require dewatering? Notes:
2.	¨	¨	Is a pit lake expected to form in the future? Notes:
3.	¨	¨	Will extraction include sulfide minerals, radioactive materials, or other geologic material that is a contaminant of concern? Notes:
4.	¨	¨	Are acidic compounds used during processing that will be contained in tailings facilities? Notes:
5.	¨	¨	Are tailings facilities constructed using any method other than the best available technology? Best available technology as of 2022 is dry filtered tailings with drainage (Morrill et al., 2022). Notes:
6.	¨	¨	Will tailings fluids discharge directly into the environment (i.e., seepage into the subsurface or leachate that drains onto the surface or into a pond)? Notes:

APPENDIX B. HYDROLOGIC IMPACTS FRAMEWORK

Neither the Checklist nor Framework should be used as a comprehensive review that covers all environmental risks, or as an alternative to intensive, site-specific hydrologic impact assessments that precede regulatory approval. Instead, the Checklist and Framework may be used to identify areas of uncertainty related to the potential for hydrologic impacts associated with lithium extraction. After applying these tools, more detailed site-specific analyses should be considered and implemented to address the areas of uncertainty. The Checklist and Framework may be paired with other assessments to identify areas or waters of concern (e.g., pairing with an ecological assessment to identify aquatic habitat that may be at risk).

5.1 PRE-DISTURBANCE

5.1.1 SURFACE-WATER HYDROLOGY: What is known about surface-water conditions prior to land disturbance and extraction activities?

This subsection applies to the following resource types, extraction methods, and surface-water features.

Resource Types	brine, clay, hard rock
Extraction Methods	evaporative concentration, direct lithium extraction, surface strip mining, surface pit mining
Surface-water Features to Consider	seeps and springs, streams and rivers, lakes and ponds, wetlands, riparian areas

1. Have surface-water features in the project area been adequately identified and characterized?
    a) If yes, characterization and monitoring efforts should continue.
    b) If no, a surface-water survey should be conducted, inventory created, and features characterized.
2. What is the location of each surface-water feature with respect to project boundary and facility activities?
    a) If the surface water is within the proposed/permitted project boundary, downstream/downgradient, or upstream and hydraulically connected, there should be high consideration for potential impacts.
    b) If no hydraulic connection and upstream of the project area, or at a distance/location outside of hydrologic area of influence (HAI), less consideration for potential impacts.
3. Is flow perennial, intermittent, or ephemeral and what are the sources of water?
    a) If flow is perennial (continuous flow year-round) or intermittent (continuous flow during certain times of the year) with baseflow contribution from local groundwater (directly from the aquifer or from seep/spring discharge), high consideration for potential impacts.
    b) If flow is ephemeral (flowing or pooling only in response to precipitation), there is lower potential for impacts. It is important to note that there is not always a clear distinction between flow classifications (i.e., perennial, intermittent, ephemeral) or the classification may change over time. For example, a drainage that has ephemeral flow during drought conditions may have intermittent flow during wet cycles.
    c) If geothermally heated springs are present that support sensitive aquatic habitat, additional considerations should be made, including comprehensive hydrologic and hydrogeologic field assessments and the development of numerical models to quantify the expected hydrologic impacts.

4. Have surface-water quantity and quality baseline conditions been established (i.e., flow, stage, temperature, physical parameters, geochemistry) for average, dry, and wet conditions over multi-year, annual, and seasonal timescales?
    a) If yes, monitoring should continue through all pre-extraction, extraction, and post-extraction periods.
    b) If no, a monitoring program should be designed and implemented to define the natural range of variability of all hydrologic baseline parameters on all necessary timescales.
5. Do the surface-water features support groundwater dependent ecosystems (GDEs) (i.e., wetlands, riparian zones, seeps, springs)? Do any GDEs provide habitat for protected species, endemic species, etc.?
    a) If yes to either of these questions, additional considerations should be made with respect to hydrologic impacts on ecosystem health. This should be considered during all monitoring and mitigation phases.
    b) If no GDEs or protected species, monitor for the development of GDEs.

5.1.2 GROUNDWATER HYDROLOGY: What is known about groundwater and aquifer conditions prior to land disturbance and extraction activities?

This subsection applies to the following resource types, extraction methods, and surface-water features.

Resource Types	brine, clay, hard rock
Extraction Methods	evaporative concentration, direct lithium extraction, surface strip mining, surface pit mining

1. Has the spatial variability of groundwater conditions (water levels, hydraulic gradients/flow paths, water quality) been adequately defined? Sources of these data may include in situ water-level measurements via observation wells, satellite data, water-sample collection, etc.
    a) If yes, monitoring should continue through the life of the project.
    b) If no, site and install additional groundwater observation wells for in situ measurements of water quantity and quality.
2. Has the temporal variability of groundwater conditions been established (e.g., groundwater levels, hydraulic gradients, water temperature, physical parameters, geochemistry) for average, dry, and wet conditions over annual, seasonal, and short-term timescales.
    a) If yes, monitoring should continue through the life of the project.
    b) If no, a monitoring program should be designed and implemented to define the natural range of variability of all hydrologic baseline parameters at all

relevant timescales. Additional observation wells should be sited and installed as necessary.

3. Has a groundwater budget been prepared to account for all inflows and outflows of the aquifers of interest (i.e., freshwater, brine)?
    a) If yes, does the groundwater budget consider all relevant scales (i.e., project area, HAI, basin wide). At a minimum, a groundwater budget should be prepared for the HAI with an additional buffer to account for uncertainty in HAI delineation.
    b) If no, a groundwater budget should be prepared.
4. Has an aquifer characterization been performed to delineate hydrostratigraphic units, aquifer extent/boundaries, and aquifer connectivity to adjacent aquifer systems and surface waters?
    a) If yes, were aquifer pumping tests conducted as part of the hydrogeologic characterization?
    b) If yes, consider this information when developing the hydrogeologic conceptual model.
    c) If unconfined, consider the hydraulic connection to surface waters, springs, and GDEs.
    d) If confined, consider that high aquifer pressure may affect flow if drilling is conducted.
    e) If no, aquifer testing should be conducted at the scale necessary to accurately characterize the aquifers over the area of interest (e.g., HAI).

5.2 LAND DISTURBANCES AND INFRASTRUCTURE: What are the potential hydrologic effects of land disturbances and new or modified infrastructure?

This subsection applies to the following resource types, extraction methods, and surface-water features.

Resource Types	brine, clay, hard rock
Extraction Methods	evaporative concentration, direct lithium extraction, surface strip mining, surface pit mining
Disturbances May Be Associated with at Least the Following Facilities	roads, power lines, buildings (e.g., processing facilities, offices, etc.), wells and well pads, open-pit/strip mines, waste-rock storage, processing/evaporation ponds, rapid infiltration basins, mine tailings, surface-water diversions, canals, culverts

1. For all facilities and land disturbances: What is the type, quantity, area (i.e., footprint), depth (if applicable), and location? To what degree will existing facilities be used?
    a) If there is no existing infrastructure or facilities at the proposed extraction site, then there is a relatively high potential for hydrologic impacts.
    b) If existing facilities will be used exclusively and no new facilities or modifications to existing facilities are required, there is less potential for hydrologic impacts.
2. For all facilities and land disturbances: What is the proximity of the disturbance/facility to surface water? Do they intersect surface waters? Are they located upstream of surface waters?
    a) If yes to any of the above, assess possible impacts on surface water caused by erosion, sedimentation, or alterations to runoff. This may lead to the degradation or loss of the surface-water resource if facilities directly intersect it.
    b) If disturbances influence surface water, alterations to runoff as well as increased erosion and sedimentation may result in degradation of local or downstream surface water.
    c) If no, erosion and sedimentation may still increase depending on the scale of disturbance and the proximity to surface water.
3. For all facilities and land disturbances: Are best management practices (BMPs) in place for runoff and erosion control?
    a) If yes, are they adequately designed to mitigate erosion, sediment transport, and deposition during a high-magnitude design storm, such as a 100-year flood frequency event? Were the following considered when selecting BMPs: infrastructure size, range of rainfall amounts (i.e., average, high), discharge

rate and volume, type of discharge (e.g., potential for contaminated flow), and proximity to downstream surface waters? Runoff/stormwater diversions may impact inflows to downstream water resources.

   b) If no, then erosion may lead to increased sedimentation in surface waters during flow events. Surface-water runoff amount and flow paths may change, impacting inflows to downgradient surface waters. Depending on the type of on-site facilities, this may also result in the release of harmful constituents into the environment.

4. Are wells to be installed for groundwater pumping and/or monitoring?
   a) If yes, what drilling methods and drilling fluids will be used? What material will be used for well construction (i.e., bentonite, cement, etc.)? Is there potential for the release of harmful chemicals into the aquifer during construction? Will hydrostratigraphic units be sealed or packed to limit mixing between aquifers? Will the well head and annular space be sealed to ensure the well does not act as a conduit for surface water/contaminants to enter the subsurface? If acids are used during well rehabilitation at any point during the life of the project, additional consideration should be given to assessing impacts on water quality.
5. Will any artificial surface depressions be constructed (i.e., ponds, rapid infiltration basins [RIBs])?
   a) If yes, how many process ponds and RIBs will be constructed and what are the dimensions of each? Determine the proximity of RIBs and ponds to surface water and groundwater and controls to prevent infiltration, such as liners. What is the area and volume per pond? Will artificial depressions capture precipitation during storm events or impact local runoff?
6. Will tailings or waste rock be produced during extraction activities?
   a) If yes, what is the material? What is the design and dimensions of storage facilities? What is the proximity of the storage facility to surface water and groundwater? What controls are in place to prevent infiltration and contamination, such as liners. How will slopes be constructed?

5.3 EXTRACTION AND OPERATIONS

5.3.1 LITHIUM BRINE AND FRESHWATER EXTRACTION: What are the hydrologic effects of brine and freshwater extraction and facility operation?

This subsection applies to the following resource types, extraction methods, and surface-water features.

Resource Types	brine, clay, hard rock
Extraction Methods	evaporative concentration, direct lithium extraction, surface strip mining, surface pit mining
Infrastructure and Processes	pumping wells for lithium-brine and freshwater, application of freshwater

<u>Groundwater and surface-water responses to groundwater extraction (evaluate for short and long-term cumulative impacts):</u>

1. What are the expected hydrologic impacts on water quality and quantity associated with groundwater extraction, including brines and freshwater?
    a) If expected hydrologic impacts are established with high confidence, take the necessary precautions based on these expectations (i.e., mitigation plan if impacts are expected).
    b) If potential hydrologic impacts associated with extraction have not been assessed, see remaining questions in this section.
2. Has a hydrogeologic conceptual model (HCM) been developed?
    a) If yes, use the HCM to make inferences about potential hydrologic impacts by considering the remaining questions in this section.
    b) If no, develop an HCM and then consider the remaining questions in this section.
3. Has the hydrologic area of influence (HAI) associated with brine and groundwater extraction been established?
    a) If yes, apply it when answering the following questions.
    b) If no, establish the HAI considering the number, location, area, design, and pumping schedule of all pumping wells, each well's depth and screened interval, aquifer(s) targeted, and groundwater conditions.
4. Is the brine/freshwater pumping schedule known (i.e., the volume extracted over time)?
    a) If yes, does pumping occur year-round, seasonally, etc., and how might this affect water resources at these timescales?
    b) If yes, what volume of brine and freshwater is extracted per year and how does this impact the annual groundwater budget, perennial yield, etc.?
    c) If yes, what are the cumulative impacts of all pumping wells for the project plus other pumping wells in the basin to water resources, aquatic ecosystems,

other water users/water rights? Consider potential water-quality and -quantity impacts for surface waters and groundwaters over short- and long-term scales.
    d) If no, consider conservative pumping assumptions (quantities and time scales on the high end) until data are available.

5. Will groundwater and brine extraction alter the natural hydraulic gradients and groundwater flow directions? Note: If pumps are used, hydraulic gradients are always impacted because of induced hydraulic head changes in the aquifer.
    a) If yes, to what extent will the gradients and flow direction be altered? How will water quality change in response to altered sediment-fluid interactions? How long until brine/water levels and quality recover in the pumped aquifer(s)?
6. Is the target aquifer hydraulically connected to adjacent aquifers?
    a) If yes, how will it impact the water quality and quantity of the adjacent aquifer? How much mixing is anticipated? Is a mitigation plan in place?
    b) If no, will the aquifer be fully replenished and over what time frame? What is the expected annual recharge/inflow rate to the aquifer?
7. Are any impacted aquifers hydraulically connected to surface waters?
    a) If yes, are there any groundwater dependent ecosystems or special-status species? Is a mitigation plan in place?
    b) If yes, what are potential water-quality and -quantity impacts? Is a mitigation plan in place?
    c) If no, continue monitoring surface waters to validate the conceptual model and confirm no impacts on surface waters.
8. Is there potential for land subsidence to occur as a result of pumping? Pumping rates should be considered, as well as lithology of the pumped aquifer(s).
    a) After or during pumping, if the strength of the aquifer material is less than the pressure of the overburden, there may be potential for the aquifer compaction.
9. Is freshwater being used for operations (e.g., dust or fire suppression, soil desalination, mixing with brines)?
    a) If yes, how might freshwater applications impact surface-water and groundwater quality/quantity? Are best management practices in place to prevent discharged water from pooling or flowing on the land surface?

5.3.2 SURFACE MINE RESOURCE EXTRACTION: What are the hydrologic effects of lithium-clay and hard-rock extraction and facility operation?

This subsection applies to the following resource types, extraction methods, and surface-water features.

Resource Types	clay, hard rock
Extraction Methods	surface strip mining, surface pit mining
Operation Processes to Consider Including	dewatering, excavation; storage of overburden, waste rock, and gangue; use of ponds or impoundments

<u>Considerations for strip mine or open-pit mine:</u>

1. Have all materials that will be extracted and deposited been representatively sampled for geochemical analysis?
    a) If yes, see remaining questions in this section.
    b) If no, perform a geochemical characterization of the geologic material.
2. How will different types of material be removed/excavated? What volume of each? Where will materials be stored?
3. Will mining occur at, below, or near the water table?
    a) If yes, assess groundwater impacts and evaluate dewatering techniques. What is the water quality of pumped groundwater? Will it be treated, stored, used in operations, or discharged away from the facility? Are there naturally occurring contaminants of concerns dissolved in the groundwater? What controls and mitigation are designed to prevent contaminants associated with mining operations from releasing into the excavated area?
    b) If no, impacts from dewatering are less likely.
4. Will mine slopes be formed that are cut slopes or fill slopes?
    a) If yes, what controls are in place to prevent slope failure? How about controls for increased erosion and rapid runoff? Will slope stability monitoring be conducted?
5. Is a pit lake expected at any point during the life of the project or post-closure?
    a) If yes, is it a terminal sink or will water pass-through? Have the following been conducted for a pit lake: water balance, conceptual model, numerical model of predicted contaminant fate and transport? Will the pit lake be treated to background surface-water quality standards?
    b) If yes, and mining is active, will inflows be removed from the pit to prevent ponding? How will water be removed (e.g., pumped and conveyed)?
6. Will sulfide minerals be extracted?
    a) If yes, conduct an acid mine drainage (AMD) assessment and attempt to isolate wastes that may generate acid. What controls, neutralization, and treatment are in place to prevent AMD?
    b) If no, AMD is unexpected as part of resource extraction, but may occur if acid is used in mineral processing (see Section 5.4.3).
7. Will naturally occurring radioactive or other contaminants of concern be extracted?
    a) If yes, what is the background radioactivity or toxicity from these sources? How will waste be handled to prevent contamination of surface or groundwater?

Considerations for overburden and waste-rock storage:

8. How will overburden and waste rock be stored? For how long?
9. Will fluid that infiltrates through the stockpile be contained with a liner and drainage system?
    a) If yes, the stockpile should be designed to drain at discharge points. If it is released into the environment, what are the water-quality concerns, mitigation solutions, and monitoring procedures at discharge points?
    b) If no, but the underlying ground surface has low conductivity, infiltrated water may saturate the lower portion of the stockpile then move laterally to toe seeps. Evaluate water-quality concerns at toe seeps.
    c) If no and the underlying ground surface has mid- to high-conductivity, uncontrolled seepage into soil and groundwater is expected. Evaluate the water-quality risks, mitigation, and monitoring for groundwater.

Considerations for ponds:

10. What is the type of pond (i.e., tailings, processing)? How will fluid and sediment be contained?
    a) If it is a tailings pond, see Sections 5.4.3 #10 and #11.
11. Will there be potential for contaminants at high concentrations in ponds?
    a) If yes, what treatment, mitigation, and monitoring are in place? Have alternatives been considered?
12. Will water be reused for facility operations?
    a) If yes, consider the pollution potential at its end use and evaluate if treatment is necessary.
    b) If no, treated discharge should be of similar quality to background surface water and compliant with regulatory guidance.
13. What measures are in place to reduce leakage from the pond into the subsurface? See Section 5.4.1 #3 for pond leakage and design considerations.

Considerations for transportation of excavated materials:

14. Are aboveground or underground storage tanks used for fuel storage? Will pipelines be used for ore slurry or fuel?
    a) If yes to either question, characterize the material stored, the tank/pipe construction, leak-detection system, and proximity to active faults, surface water, and groundwater.
    b) If no, evaluate any other engineered systems for chemicals used during transportation of excavated materials.

5.4 RESOURCE PROCESSING

5.4.1 LITHIUM BRINE: EVAPORATIVE CONCENTRATION: What are the hydrologic impacts of lithium-brine processing using evaporative concentration techniques?

This subsection applies to the following resource types, extraction methods, and surface-water features.

Resource Types	brine
Extraction Methods	evaporative concentration

Water-quality considerations:

1. Once the brine has been extracted from the subsurface, will additives be used during the evaporative concentration process to precipitate unwanted ions/salts and create a concentrated lithium brine?
    a) If yes, what are the specific additives used and quantities applied, and at which stage/pond? Will acids and bases be used to control pH at various stages? What are the on-site facilities and best management practices (BMPs) for additive storage?
2. Will any solid waste or by-products be produced during the evaporative concentration process?
    a) If yes, will mineral compounds be precipitated from the brine (e.g., halite, sylvite, calcite, gypsum)? If so, in what sequence (at which stage/pond) and at what rate? How are solid waste and by-products stored, treated, and transported? For example, will precipitated material be dredged from the pond and transported to stockpiles or a sludge-containment reservoir?
3. Are there measures in place to reduce leakage and detect leakage from the evaporation pond into the subsurface?
    a) If leakage reduction relies on low-permeability soils beneath and surrounding the pond, has a soil survey been conducted? Is a continuous low-permeability layer present beneath the pond and if so, what is the depth to the top of the layer and its thickness? How are any permeable soil zones managed (e.g., replaced with low permeability clays)?
    b) If pond liners are used, what kind of material is used (Hypalon, polyvinyl chloride, polypropylene)? How are strips combined/sealed (e.g., adhesive, welding)? Are all liners leak-checked prior to use? Is a leak detection system co-installed with the liner?
    c) Are precipitated salts used to reinforce the pond floor/walls?
    d) What measures are taken to monitor for leaks in the subsurface (i.e., conductivity, temperature, and/or moisture sensors; piezometers)? If a leak is detected, is an action plan in place to find and repair the leak?

4. Are any additional processes used to augment the evaporative concentration process that could impact water quality directly or indirectly?
    a) If yes, what are the techniques, what materials/additives are needed? For example, the use of alumina columns for selective adsorption or co-precipitation of lithium.
5. Is the transfer of brines between ponds driven by pumps?
    a) If yes, how are pumps powered (e.g., diesel generators)? What BMPs are in place for all fuel storage, conveyance, etc.?
    b) If no, does the method of transfer (e.g., gravity or another technique) pose risk for surface or groundwater contamination?
6. Will lithium-depleted brine be returned to the subsurface via reinjection wells or rapid infiltration basins (RIBs)?
    a) If yes, how will the lithium-depleted brine be conveyed to the RIBs/injection wells (e.g., gravity fed or pumped through pipeline)?
    b) If yes, will the proposed technique return the lithium-depleted brine to the source aquifer or a different aquifer? A great potential hazard is posed if fluid originally from a brine aquifer is infiltrated or injected into a freshwater aquifer.
    c) If yes, how does the water quality of the return brine compare to the quality of the aquifer fluid? If RIBs are used, has an assessment of shallow water quality been conducted? Has geochemical characterization of the sediment in the unsaturated and saturated zones been performed?
7. Upon completion of the evaporative concentration process, is the lithium-concentrated brine refined on-site?
    a) If yes, what additives, acids, etc., and procedures are used to produce the final lithium product? What are the BMPs in place for storing, transporting, and using these materials to prevent spills, contamination, etc.? Additives may include chemicals, acids, and bases that could degrade water quality if there is an environmental release.
    b) If no, the lithium-concentrated brine is transferred for off-site processing. What BMPs are in place for transporting the brine? Is the brine transferred via a pipeline using pumps, trucked, shipped by railroad? What is used to power any pumps (e.g., diesel generators)?
8. Post-refinement, is any slurry or filtrate returned to the solar pond for further processing for lithium (or other materials of interest)?
    a) If yes, what methods will be used to convey/transport these materials and what are potential threats to water quality?
    b) If yes, the evaluation process should recommence at Section 5.4.1 #1.

<u>Water-quantity considerations:</u>

9. Will water from the brine be removed through evaporation?
    a. If yes, what volumes of brine and freshwater are consumed through evaporation and for extraction operations over varying time frames (seasonal, annual, life of the project). What percent of the total volume extracted is lost

to evaporation? How many ponds are used, what are the pond dimensions, how much brine per pond, and what are the evaporation rates per pond? How do seasonal differences between evaporation and precipitation rates impact processing timing, duration, and total water loss? Are any steps taken to reduce evaporation or recapture evaporated water? What is the initial lithium concentration of the extracted brine and how is this concentration expected to change over time? How do lithium concentrations relate to the extracted brine volume (and volume evaporated)?

10. Will lithium-depleted brine be returned to the subsurface via reinjection wells or RIBs?
    a. If yes, what is the anticipated volume of brine, treated water, etc., infiltrated (through RIBs) or reinjected (through wells) into the subsurface? What percentage of the volume pumped from the brine aquifer is returned to the aquifer? Reinjecting or infiltrating brines/waters result in a temporary and localized increase in water pressure, or groundwater "mounding," that will alter natural groundwater flow paths. If brine is returned to a shallow aquifer that is connected to surface water, will surface-water flow/stage be impacted? Could this have an impact on groundwater dependent ecosystem, special-status species, or other water users/water rights holders?
11. Is freshwater needed during processing?
    a. If yes, how much freshwater is needed during processing and what is the source of the freshwater? For example, freshwater may be used during refinement to prevent salts from crystallizing. If water is sourced from local freshwater aquifers, what are the hydrologic impacts (see Sections 5.3.1 #4 and #5).

5.4.2 LITHIUM BRINE: DIRECT LITHIUM EXTRACTION: What are the hydrologic impacts of lithium brine-processing using direct lithium extraction?

This subsection applies to the following resource types, extraction methods, and surface-water features.

Resource Types	brine
Extraction Methods	direct lithium extraction

Water-quality considerations:

1. Once the brine has been extracted from the subsurface, will direct lithium extraction (DLE) be performed at on-site facilities?
    a) If yes, see questions below.

   b) If no and transferred to an off-site processing facility, what are the transportation logistics and BMPs in place to prevent environmental releases during transfer?
2. Is the DLE technique known? Many DLE techniques are proprietary and limited information may be available.
   a) If yes, what is the DLE technique?
   b) If yes, will additives be used to convert the original lithium compound to the final lithium product? What are the additives, what volumes will be added, and at which stage of the extraction process? For example, sodium carbonate may be added to convert lithium chloride to lithium carbonate. What is the pH of the incoming brine, and will acids/bases be used to control pH? Will brine polishing take place to remove unwanted ions (e.g., pass brine through ion-exchange system to replace magnesium and calcium with sodium)?
   c) If no, there may be relatively greater risk for hydrologic impacts. Assume greater risk until the processing technique is known and associated hydrologic risks identified.
3. Will lithium-depleted brine be returned to the subsurface via reinjection wells or RIBs?
   a) If yes, see Section 5.4.1 #6.

<u>Water-quantity considerations:</u>

4. Will lithium-depleted brine be returned to the subsurface via reinjection wells or RIBs?
   a) If yes, see Section 5.4.1 #10.

5.4.3 SURFACE MINE RESOURCE PROCESSING: What are the hydrologic impacts of lithium-clay and hard-rock processing?

This subsection applies to the following resource types, extraction methods, and surface-water features.

Resource Types	clay, hard rock
Extraction Methods	surface strip mining, surface pit mining

1. What chemicals are present on-site for the separation, roasting, acid leaching, precipitation/purification, conversion processes for the refinement of the final lithium product?
2. Are the chemicals potentially hazardous if released into the environment?
   a) If yes, evaluate their potential for surface-water and groundwater contamination. How easily can it mobilize into the environment? Is the substance water soluble? Evaluate each substance’s polarity, specific gravity, and potential for conversion or biological transformation.

3. Will hazardous chemicals be stored in aboveground or underground storage tanks? Are pipelines also used?
    a) If yes to any, characterize the material stored, the tank/pipe construction, leak detection system, and proximity to faults, surface water, and groundwater.
    b) If no, evaluate any other engineered systems for transportation and storage of hazardous chemicals used in processing.
4. Will acidic compounds be used in processing?
    a) If yes, conduct an acid mine drainage (AMD) assessment. Isolate wastes that may generate acid and neutralize this waste. What controls and treatments are in place to prevent AMD?
    b) If no, AMD is unexpected as part of processing but may occur if sulfide minerals are extracted (see Section 5.3.2 #6).
5. Is waste from processing mixed with waste from extraction?
    a) If yes, evaluate waste management procedures to address water-quality concerns for all combined material.

<u>Considerations for solid waste from processing:</u>

6. Determine the type of material and storage method. Is the best available technology employed?
7. Will solid waste be treated prior to storage/disposal?
    a) If yes, determine the method and efficiency of treatment.
    b) If no, analyze water-quality risks associated with untreated waste. What is the potential for contamination of surface-water runoff or groundwater seepage? Will there be water-quality monitoring?
8. Will fluid that infiltrates through the tailings facility be contained with a liner and drainage system? Will the facility be zero discharge?
    a) If yes, but not zero discharge, drained water will be concentrated at discharge points and released into the environment. What are the water-quality concerns, mitigation solutions, and monitoring procedures at discharge points?
    b) If no, are there other engineered controls to prevent infiltration and seepage? What are the water-quality concerns, mitigation solutions, and monitoring procedures for surface water and groundwater?
9. Will tailings be deposited into an excavated area?
    a) If yes, analyze BMPs to mitigate seepage of leachate into soil and groundwater. If seepage is possible, what compounds could be mobilized? Will there be water-quality monitoring? What is the predicted fate and transport of leached constituents?

<u>Considerations for tailings pond or liquid waste from processing:</u>

10. Determine the type of material and storage method. Will a tailings pond or subaqueous tailings be used?
    a) If yes, these methods should be reconsidered because they are potentially hazardous to environmental safety, especially if an upstream dam is used. What are the treatment, stability monitoring and water-quality monitoring, mitigation, and containment procedures?

b) If no, is liquid waste from waste rock, dry-stack tailings or seepage collected? Analyze water-quality risks associated with waste. What is the potential for contamination in surface-water runoff or groundwater seepage?

11. Are ponds designed to be impermeable with zero discharge?
    a) If yes, the pond will retain water, which may reduce dam stability and increase the risk of overtopping or failure. See Section 5.4.1 #3 for pond leakage concerns. How will overtopping be prevented during normal operations? During flooding events? What is the slope-stability monitoring plan?
    b) If discharge is expected, assess flow paths, and water quality at the discharge point. Are BMPs designed for contamination prevention and mitigation?
    c) If the pond is not impermeable but no discharge is expected, seepage will occur into groundwater and through the embankment face. What compounds could be mobilized? What is the predicted fate and transport of leached constituents?

<u>Considerations for both solid and liquid waste:</u>

12. Will surface-water resources and associated ecosystems be severely impacted if tailings fail to contain contaminants?
    a) If yes, tailings failure is accompanied by high consequences and the tailings disposal method and location should be critically analyzed or reconsidered.
13. Does the surface-water and groundwater management plan address the potential water-quality impacts associated with tailings?
    a) If yes, are impacts on short-term and long-term water quality sufficiently mitigated with a high degree of certainty, especially where contaminants could reasonably affect surface-water habitat or groundwater dependent ecosystems?
    b) If no, identify and resolve overlooked or uncertain systems. Tailings are a major pollutant source.

5.5 CLOSURE OF A LITHIUM EXTRACTION FACILITY: What are the hydrologic impacts related to facility closure activities?

This subsection applies to the following resource types, extraction methods, and surface-water features.

Resource Types	brine, clay, hard rock
Extraction Methods	evaporative concentration, direct lithium extraction, surface strip mining, surface pit mining
Areas/processes to consider include	regrading and revegetation, facilities (e.g., processing, fueling, etc.), open-pit or strip mine, waste-rock storage, ponds, rapid infiltration basins, tailings

1. Will surface conditions (e.g., topography, grade, soil, vegetation) be restored to pre-extraction conditions?
    a) If yes, over what time frame?
    b) If yes, what are the best management practices to reduce impacts on erosion, stormwater, and sedimentation as facilities are deconstructed and removed and the land is regraded?
    c) If yes, when will revegetation to pre-extraction levels be achieved? Prior to vegetation regrowth and root development, soil stability may be compromised. Erosion from wind and water, as well as slope failure can result in sedimentation of surface waters. Pre-extraction evapotranspiration rates may not be achieved until vegetation is fully grown. How will this impact the local and regional water balance, surface-water flow, etc.?
    d) If no, where will land-surface conditions not be restored? What are the short- and long-term hydrologic effects of not returning these areas to pre-extraction conditions (i.e., runoff, erosion, and sedimentation)? What about impacts on excavated areas, such as groundwater/surface water interaction at a pit lake?
2. Will subsurface conditions (e.g., groundwater levels and flow paths, water chemistry, soils) be restored to pre-extraction conditions?
    a) If yes, how will this be achieved? Will pumping wells be plugged and abandoned to prevent surface contaminants from migrating downward through the well/borehole? If a surface mine required dewatering, will water levels completely recover? How long after pumping stops will water levels rebound?
    b) If no, what will be the long-term consequences for water resources?
3. Will excavated areas be backfilled?
    a) If yes, what are the methods to backfill surface depressions? Will the original rock/soil/sediment be used for backfilling? If the original stratigraphy is altered, how will the presence of homogenized/disturbed rock and soil impact soil physics, water infiltration, groundwater levels, and surface-water discharge?

b) If yes, has the original geologic material been exposed to the atmosphere? The material may be oxidized, which can change geochemical conditions. How might this impact water quality as water percolates through the disturbed rock or soil? Focus should be put on increased potential for leaching metals, acid mine drainage, and impacts on hydraulically connected surface-water bodies. Geochemical models can be developed to predict long-term effects to water quality associated with water-rock interaction.
c) If no, what are the geochemical implications to surface water and groundwater of not restoring these areas and leaving them exposed to the atmosphere, precipitation, etc.?
d) Are surface water and groundwater being monitored for water-quality and quantity impacts during closure? What is the hydraulic connectivity between areas used for ponds, rapid infiltration basins, tailings, excavation/backfill and surface-water and groundwater systems? Impacts on groundwater and surface water may be the result of delayed impacts of extraction activities or directly related to closure activities (e.g., regrading). Aquifer hydraulic properties may cause delayed groundwater and surface-water impacts, such as aquifers with low hydraulic conductivity that promote long residence times.

5.6 POST-CLOSURE OF A LITHIUM EXTRACTION FACILITY: What are the hydrologic impacts post-closure of a lithium extraction facility?

This subsection applies to the following resource types, extraction methods, and surface-water features.

Resource Types	brine, clay, hard rock
Extraction Methods	evaporative concentration, direct lithium extraction, surface strip mining, surface pit mining

1. Once the lithium extraction site has been reclaimed, will surface-water and groundwater monitoring continue to identify any long-term impacts?
   a) If yes, will data collection be adequate to identify any long-term or delayed effects to surface water and groundwater from extraction activities (e.g., resource extraction, processing) and closure activities (e.g., restoration, reclamation)? What type of monitoring will be performed (i.e., groundwater/surface water quantity/quality)? What is the duration and frequency of data collection? Is monitoring adequate to identify any unexpected chemical releases into the environment (e.g., leakage through lined facilities)?
   b) If yes and there was an open-pit mine, will a pit lake remain on-site? If yes, see pit-lake guidance in Section 5.3.2 #5.
   c) If no, a surface-water and groundwater monitoring plan should be developed that addresses potential impacts on long-term surface-water and groundwater quantity and quality.
2. Will the physical stability of tailings and mine slopes be monitored? Will this be coupled with groundwater seepage monitoring?
   a) Assess stability by evaluating the slope angle and the internal mass strength. What is the factor of safety to prevent failure?
   b) If surface mining, are caps and covers (such as on tailings) adequately designed for the current climate and for climate change scenarios with increased extreme weather intensity and frequency?
   c) If no, a monitoring plan should be developed. Slope failure will have significant consequences for erosion and sedimentation, as well as containment of pollutants.
3. Will the long-term environmental geochemistry be evaluated and managed?
   a) If yes, what is the potential for negative changes in geochemistry over time, such as the development of an oxidizing environment, materials that exceed their acid-buffering capacity, or hydrothermal alterations?
   b) If yes, will numerical models predict contaminant fate and transport for a range of conditions that address uncertainties? Does it have a sufficiently long period of prediction?

c) If yes, will monitoring be conducted at observation points (surface water or wells) to verify or inform predicted concentrations, timing, and extent, which can be used to calibrate and update performance predictions?
d) If yes, will remediation occur if concentrations exceed predetermined thresholds? What will remediation entail?
e) If no, considering developing a geochemical modeling and monitoring plan. A numerical model can be developed to predict contaminant transport and fate. Monitoring plans are useful to verify or update the geochemical model.

STANDING DISTRIBUTION LIST

Michael Clifford
The Nature Conservancy
Southern Nevada Field Office
8329 W. Sunset Road, Suite 200
Las Vegas, NV 89113
michael.clifford@tnc.org

Laurel Saito
The Nature Conservancy
Nevada Field Office
1 East First Street
Suite 1007
Reno, NV 89501
laurel.saito@tnc.org

Nevada State Library and Archives
State Publications
100 North Stewart Street
Carson City, NV 89701-4285
NSLstatepubs@admin.nv.gov

Archives Getchell Library
University of Nevada, Reno
1664 N. Virginia St.
Reno, NV 89557
cklenke@unr.edu

Document Section, Library
University of Nevada, Las Vegas
4505 Maryland Parkway
Las Vegas, NV 89154
sue.wainscott@unlv.edu

†Library
Southern Nevada Science Center
Desert Research Institute
755 E. Flamingo Road
Las Vegas, NV 89119-7363

All on distribution list receive one PDF copy, unless otherwise noted.

† 2 copies; CD with pdf (from which to print)