Direct extraction lithium processes: the challenges of spent brine disposal

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ABSTRACT: The significant role of lithium in the continued development and expansion of renewable and clean energy has led to an increase in the demand for projects involving the extraction of lithium from shallow brines, particularly in the 'lithium triangle' – Salar de Atacama in Chile, Salar de Uyuni in Bolivia and Salar de Hombre Muerto in Argentina – to be developed.

In line with increased demand, several companies have developed direct extraction processes and new technology to recover the lithium contained in brine. These direct extraction processes have emerged as an alternative to the conventional processes that are based on increasing the concentration of lithium through solar evaporation in evaporation ponds. The advantages of direct extraction processes include lower costs, shorter ramp-up periods and reduced dependence on climate.

However, management of spent brine tailings can be a significant issue if planning is inadequate. Direct extraction processes generate large amounts of spent brine (brine with a reduced lithium concentration), which may potentially affect the lithium-rich brine concentration. To prevent tailings disposal from affecting the lithium-rich brine, diligent engineering design is required. A key aspect in achieving cost-efficient direct extraction processes is providing solutions that avoid extensive use of liner in the disposal ponds or high operational costs.

This paper showcases recent experience with spent brine tailings management at projects in the lithium triangle, and experience in brine potash projects, which are similar in terms of mining methodology.

1 INTRODUCTION

Lithium is an important chemical element with many end-uses, but it is most commonly known for its powerful electrochemical properties that are harnessed in the form of efficient, lightweight lithium-ion batteries. This critical commodity keeps our world charged and connected, and has a significant role to play in the continued development and expansion of renewable, clean energy to power our world. As global demand for lithium increases, new projects and/ or increased production is required.

Lithium was traditionally extracted from minerals in igneous rocks such as pegmatites (mainly spodumene), clay minerals (mainly hectorite), and from naturally-enriched brines hosted within Salars (salt lakes) in hyper-arid regions. Following the increased demand for the mineral, projects involving the extraction of lithium from shallow brines, particularly in the 'lithium triangle' – Salar de Atacama in Chile, Salar de Uyuni in Bolivia and Salar de Hombre Muerto in Argentina – have gained interest from a market perspective, becoming the preferred alternative lithium source. The investor's preference for lithium brines is based on the environmental, logistical and cost advantages during initial prospecting, exploration and development of the project. Additionally, important by-products such as potassium (K), boron (B) and sulphate (SO_4^{-2}) can be extracted from these brines and commercialised.

The increased market interest has also driven the technical evolution of the extraction process. Direct extraction technologies are an alternative to the conventional production processes. The conventional process is based on increasing the concentration of lithium through solar evaporation in evaporation ponds. The main advantage of direct extraction processes is the shorter period between extraction commencing and the first lithium carbonate (Li_2CO_3) batch being produced (almost immediate), compared with the time required to obtain a highly concentrated brine to feed to the process plant in a conventional extraction process (2 to 3 years, depending on factors such as initial concentration, final concentration requirements and climate). Other advantages of direct extraction processes include lower capital costs and reduced dependence on climate.

A generic flowchart of the two extraction alternatives is presented in Figure 1 and Figure 2, which show indicative ranges of lithium ion (Li^+) concentration and brine/water amounts based on a unit value intake. In conventional extraction methodology, most of the water in the raw brine is evaporated before the brine arrives at the final process plant. In contrast, direct extraction methodologies do not result in significantly reduced brine/ water volumes. This difference has a significant impact on the amount of spent brine disposal volumes.

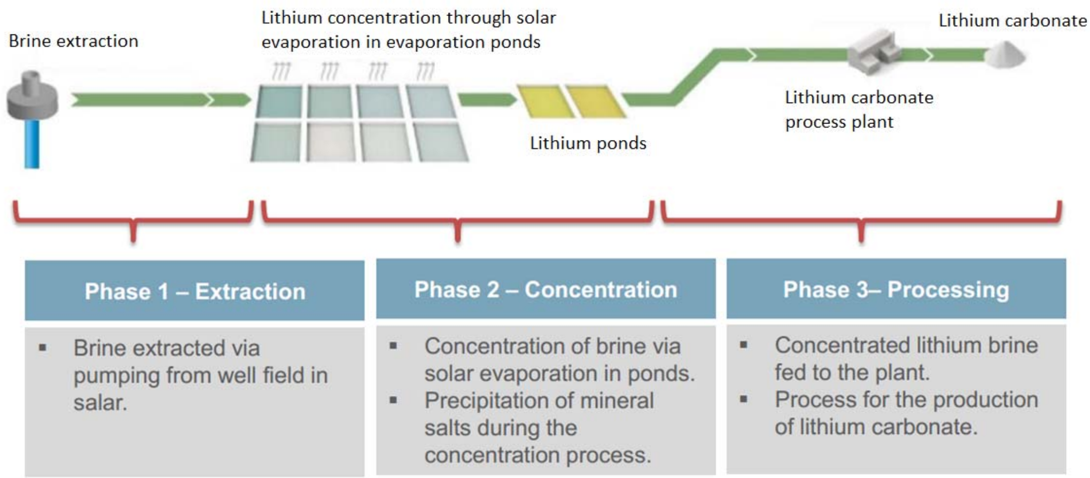

Figure 1. Conventional solar evaporation process flowchart – from Lithium Americas 2017.

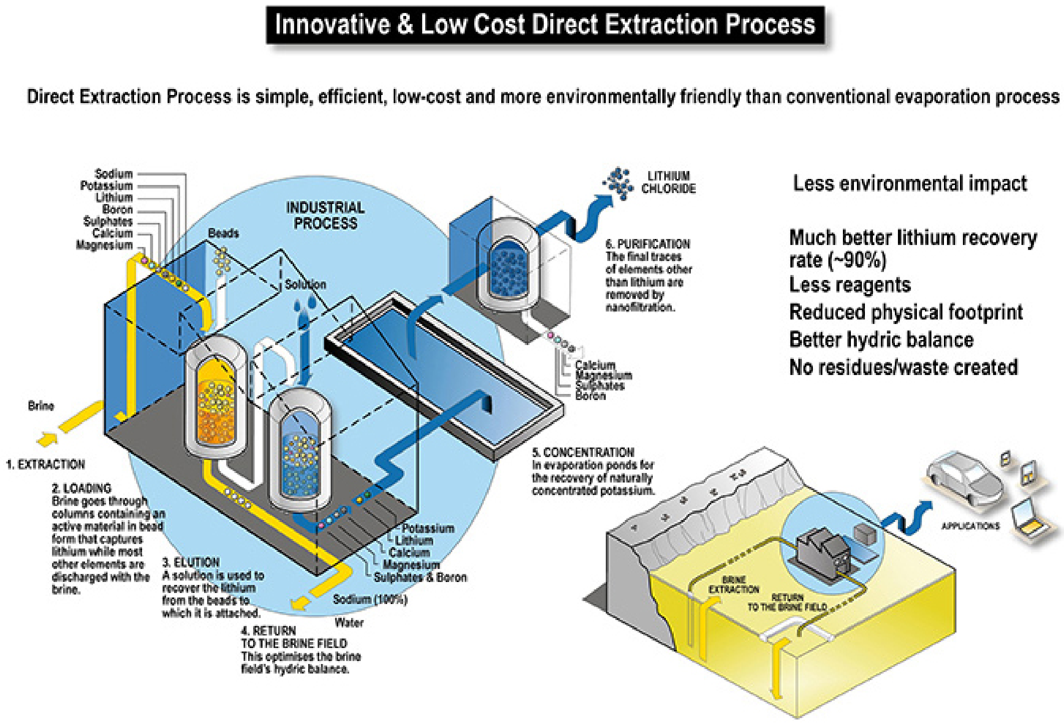

Figure 2. Direct extraction process flowchart – from article in business.gov.au

The specific details of brine lithium mining projects, and the risks and implications of the spent brine disposal are addressed in the following sections. Recent experience in the management of spent brine tailings at projects in the lithium triangle is also presented. In a wide sense, the presented concepts can be applied to a wide variety of brine projects, i.e. both conventional evaporation and direct extraction processes for lithium (Li), potassium (K), boron (Bo), sulphate ($SO4^{-2}$) and others.

2 BRINE RESOURCES – DYNAMIC RESOURCE

Economic concentrations of lithium-bearing brines occur in Salars (salt lakes) in select arid regions around the world. These brines account for over half of global lithium production in 2017 (USGS, 2017). Brines are unique amongst mineral deposits because the valuable elements are contained in a mobile environment, and the brine composition and grade have a temporal component, before and during extraction. Because each Salar can exhibit highly variable characteristics, there are no 'rules of thumb' for evaluating and classifying resources. The chemical and hydrogeological complexity of closed evaporite basins makes the exploration, evaluation, and reporting of Mineral Resources for lithium brines challenging.

Lithium mining from highly enriched brines is significantly different to classic hard-rock mining, given the fluid nature of the resource host (i.e. the brine). Classic mining is exempt from issues related to the fluid nature of the resource host, with the resource in solution, such as the potential for lithium concentration variation across time.

Given the nature of this type of project, brine resource and reserve estimation requires the application of specialised hydrogeological knowledge, i.e. hypersaline solution theories for groundwater dynamics modelling, and chemical processing engineering, i.e. brine processing for high-purity Li_2CO_3 extraction. In line with this, the hydrogeologist becomes the mining engineer, and the chemical engineer becomes the process mining engineer (Braun et al., 2016).

Brine extraction for surface processing and recovery of potash, lithium and industrial salt requires the application of traditional hydrogeological theories of hypersaline solutions. Such brines present additional technical challenges in comparison to fresh water, due to the effects of density (e.g. 1.2 g/cm^3), density-driven multi-chemical composition flow on a large scale, and interaction between brines and fresh water over the course of the production period. Surface processing facilities require estimation of brine composition over time. Therefore, the hydrogeologist is tasked with balancing extraction rates from multiple production wells, locating the production wells in space (and time), predicting chemical composition of the pre-pumping and extracted brines and monitoring depletion of a 'dynamic' resource. Each of these parameters can have a significant impact on project economics.

Parameters such as effective porosity, permeability ('hydraulic conductivity' adjusted by density and dynamic viscosity), anisotropy, aquifer configuration (extent, thickness and heterogeneity), and wellfield efficiency are key in the estimation of resources and reserves for brine extraction projects. During the pre-feasibility and feasibility stages, an accurately built numerical groundwater model is required to develop a production plan (Braun et al., 2016).

3 SPENT BRINE DISPOSAL MANAGEMENT

Direct extraction processes generate large amounts of spent brine (brine with a reduced Li^+ concentration), which may potentially affect the concentration of lithium-rich brine. From an environmental point of view, the disposal of spent brine usually does not present major challenges because the chemical characteristics of the spent brine are usually similar to the initial resources; however, the mobile nature of highly enriched brines may turn the disposal of spent brine into a real challenge, given the potential effects of this additional flow source over the 'dynamic' resource.

Two usual strategies are considered for disposal of spent brine under direct extraction process:

1) Reinjection of spent brine back into the basin
2) Disposal in evaporation ponds.

Each one of these strategies has its own benefits and drawbacks and, in order to prevent negative impacts on the resources (i.e. dilution), adequate planning with respect to the spent brine management should be undertaken as part of the early stages of the project planning development.

3.1 *Spent brine reinjection*

Pumping (reinjecting) spent brine back into the basin is the traditional solution considered for the conventional evaporation process. The brine is returned to its original environment, with no impacts on the surface.

In this regard, the pumping solution is ideal. However, with large volumes of spent brine, it is likely that lithium-rich brine concentrations may become affected over time. As stated earlier, the valuable minerals in shallow brines are contained in a mobile environment, and the brine composition and grade have a temporal component, before and during extraction, driven by multi-chemical composition flow, and interaction between brines and fresh water over the course of the production period.

The inclusion of reinjection in the hydrodynamics (in addition to the rich brine hosted in the Salar and the fresh water sources) adds another source of dilution. This extra source needs to be balanced when considering the production wells (i.e. setting extraction rates, and locations over time), and when predicting chemical composition of the brines and forecasting depletion of a 'dynamic' resource. The extra source, i.e. the spent brine inflow, can have a significant impact on project economics, which is potentially negative if not properly considered.

High costs may also be an issue when volumes of spent brine are considerable. Capital expenditure for an alternative like this is mainly linked to the installation of pipelines and feed wells to appropriate positions (and depths). Operational costs are mainly driven by energy consumption involved in forcing brine into a saturated basin.

With the increase in volumes, strategies for controlling dilution may lead to increasing capital expenditure in the development of the discharge points. On the other hand, energy costs that are related to flow rates of the discharge and the characteristics of the aquifer, will also increase. Moreover, the discharge strategy should be included from early stages (pre-feasibility and feasibility) in the accurately built numerical groundwater model required to develop the production plan (and estimate resources and reserves), which will increase the complexity of the design.

Therefore, as this option is still viable, it should be considered as part of a holistic approach, from early stages of the project development, as it will be an inportant component of development of the extraction plan. Moreover, it will be an additional element in the development of a commercial-scale brine extraction project, to be considered with similar concepts to the ones mentioned in Braun et al., 2016 and Houston et al, 2011.

3.2 *Disposing in evaporation ponds*

Disposal of spent brine in evaporation ponds seems counter-intuitive considering that a key aspect of the cost efficient direct extraction processes is providing an alternative solution that avoids the need for expansive evaporation ponds, and in particular the use of an impermeable liner – a major cost component in conventional evaporation processes. However, if seepage is not controlled (no lining is used), spent brine tailings can have a significant impact on the mineral-rich brine.

Nonetheless, taking advantage of the brine's characteristics and the environment hosting the brines, a holistic solution can be developed. This is solved by undertaking a design that balances evaporation, crystallisation and seepage to keep the recycled brine inflow to the basin at a controlled rate (and potentially at an increased mineral concentration – similar to the raw brine concentration), while developing a hybrid evaporation pond-salt stack using the reject material.

While this solution has an impact over the surface (salt landforms are developed), the mineralogical contents do not differ from the original ones in the environment, as there are no considerable additions (in terms of chemical components).

In addition, the risk of lithium-rich brine concentrations becoming diluted on time are reduced by two related aspects considered in this type of design concept, namely:

1) A reduction in the inflow rate
2) A potential increase in the mineral content of the spent brine, with a similar order of magnitude to the one in the raw brine hosted in the Salar.

Costs to be considered in the development of evaporation disposal strategy should include, among others, land to be commissioned by the salt stack (area will be related to production and climatic conditions), earthworks for containment structures, and pipelines for disposal lines. The availability of land, and the earthworks required for the containment structures, will be the critical costs.

In return, while the discharge strategy needs to be kept in mind from the early stages of the project (pre-feasibility and feasibility), it will not be necessary to include seepage in the numerical groundwater model required to develop the production plan. This reduces the complexity (and uncertainties) of the production plan design, and the requirement for iterations, allowing for a more robust estimation of the resources and reserves.

Therefore, when adequately developed from early stages of the project, this option will allow the production plan development problem to be decoupled from the brine disposal problem.

4 SHOWCASE OF DISPOSAL DESIGN STRATEGY

During the past few years, SRK has been involved in the development of a series of brine projects around the world, and particularly in the Lithium Triangle.

As part of the services provided, SRK has developed an in-house methodology to manage spent brine disposal through a holistic evaporation-stacking disposal strategy.

To showcase the magnitude of the disposal volumes, 'average' values for direct extraction process projects are presented for the following design parameters:

1) Lithium production rate: 25ktpa Li_2CO_3
2) Average raw brine concentration: 400–700 mg/l Li
3) Overall efficiency: ~50%
4) Spend brine disposal rate: 1,500–3,000 m^3/hr of brine
5) Brine evaporation rates in the lithium triangle: 4–8 mm/day.

With the objective of achieving an economically feasible design with minimum impact over the 'dynamic' resource, the starting point for the disposal design was the study of the basin flow conditions and mineral concentrations. This considers the nature of the basin (mature - halite dominant and immature - clastic dominant, as per Houston et al., 2011), aquifer geometry, porosity, brine grades, and location of the fresh water inflows. In particular, because the disposal strategy is to keep spent brine near the surface, the availability of low conductivity zones that can be used as a 'natural' liner will be of interest. As these aspects are also part of the requirements for evaluating brine prospects, only minor complementary studies need to be considered to complete this.

Closely related to this first assessment is the extraction plan. While this is the main aspect in the development of a brine prospect, and the objective is to avoid interaction between disposal and extraction, the knowledge developed during this stage can be of great value for the selection of the disposal site. In other words, the extraction plan will provide a holistic view of all aspects considered in the basin data review, which will support the site selection.

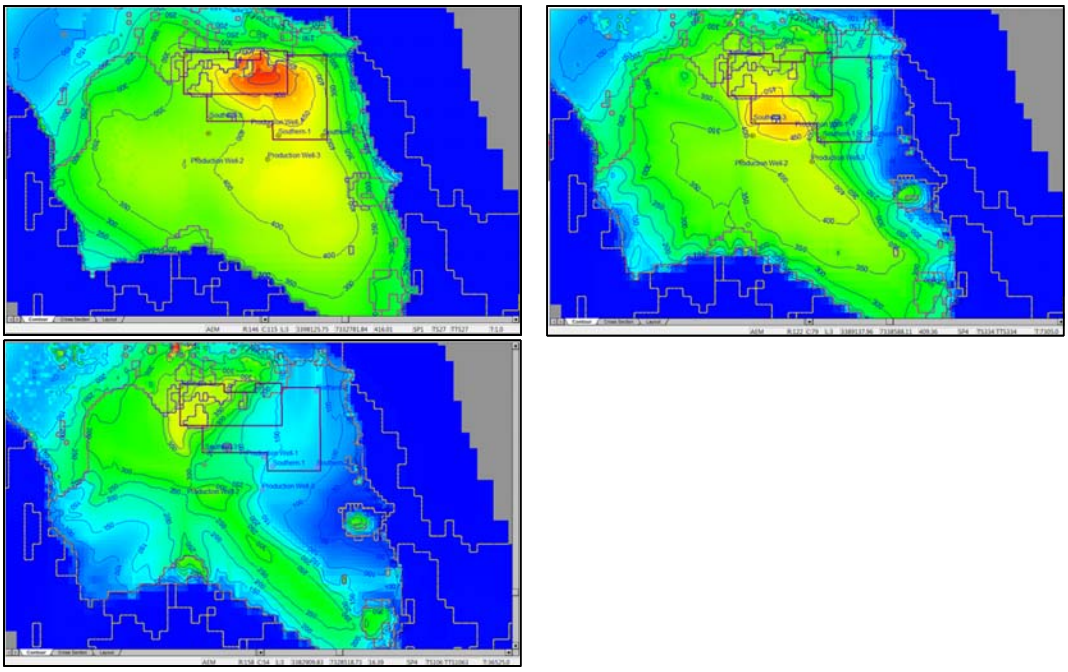

Figure 3. Li^{+} concentration evolution through production for a project in the lithium triangle -situation before production start and after 20 and 100 years of production – SRK Consulting (2016b)

Once a site-wide study of the potential disposal areas has been completed, and the benefits and disadvantages in terms of potential impact over the resource are identified, specific engineering and management aspects related to disposal can be considered. Among them, critical aspects will be the disposal area sizing, and the decision for tolerance/ allowance for seepage and infiltration (quantity and quality). The required area of disposal is linked to the evaporation capacity of the site and the expected spent brine flow, and the tolerance/allowance for seepage and infiltration. The brine storage volume (and level) is to be kept at minimum, both to avoid increasing earthworks (for storing/ retaining the increased brine volumes), and to maintain a low water head (main driver for infiltration). For a project such as the example used here, and depending on the Li^{+} concentration in the spent brine, an area between 500 ha and 1000 ha should be considered to achieve the objectives.

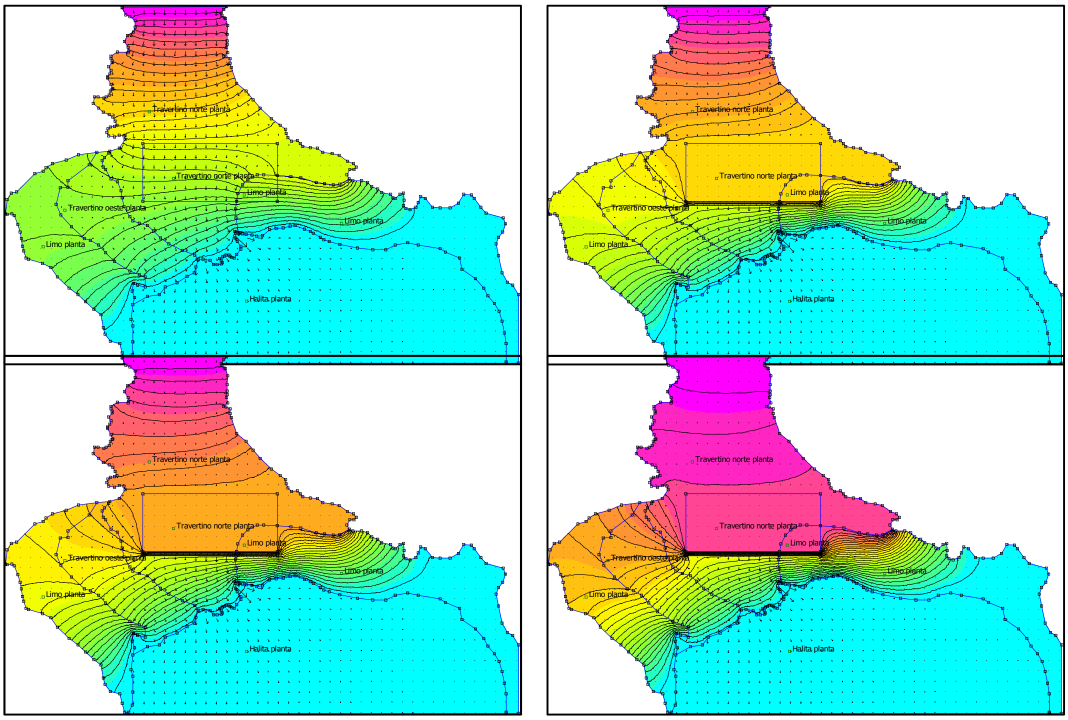

Figure 4. Recharge flow evolution over time for a project in the lithium triangle. Situation before production start and after 1, 5 and 20 years of production – internal database, SRK.

Given the areal requirements, reduction of the earthworks through the life span of the project should also be considered. The economic and financial impact of diligent engineering of the disposal facility can be significant, given the length of the facility's perimeter. Aspects to consider include topographical characteristics of the area and the availability of local materials.

The selected area is to be assessed by undertaking an integrated mass balance to understand the evolution of the evaporation pond-salt stack hybrid disposal, focusing on reducing earthworks, and/or delaying them, while controlling seepage (quality and quantity). To do this, a design that achieves balance between evaporation, crystallisation and seepage should be undertaken, to maintain inflow of the recycled brine to the basin at a controlled rate (and potentially at an increased mineral concentration – similar to the raw brine concentration), while developing a hybrid evaporation pond-salt stack using the reject material.

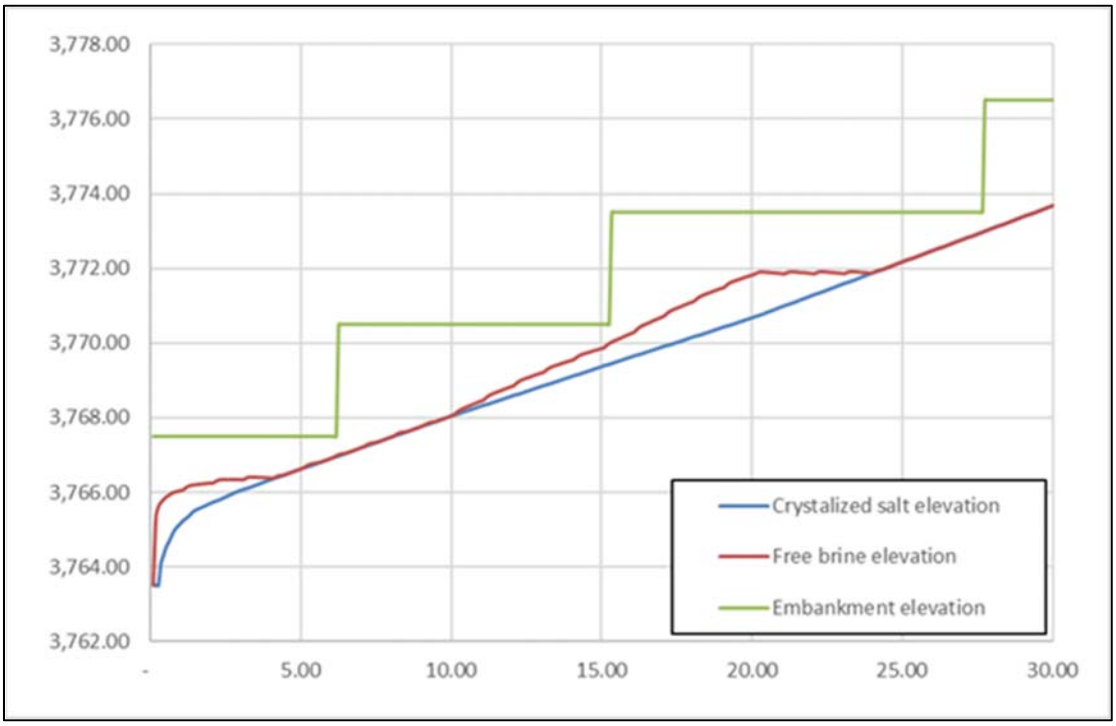

Figure 5. Brine storage level, crystallized salt elevation and embankment raising evolution over time for a project in the lithium triangle – internal database, SRK.

In terms of earthworks reduction by using local material, taking advantage of the crystallised salt, can reduce development costings significantly. However, a good understanding of the specific characteristics of this material when used for structural purposes is needed, i.e. being rock, it can dissolve, creep and have significant permeability; interaction with the disposal facility, as a whole,should be studied.

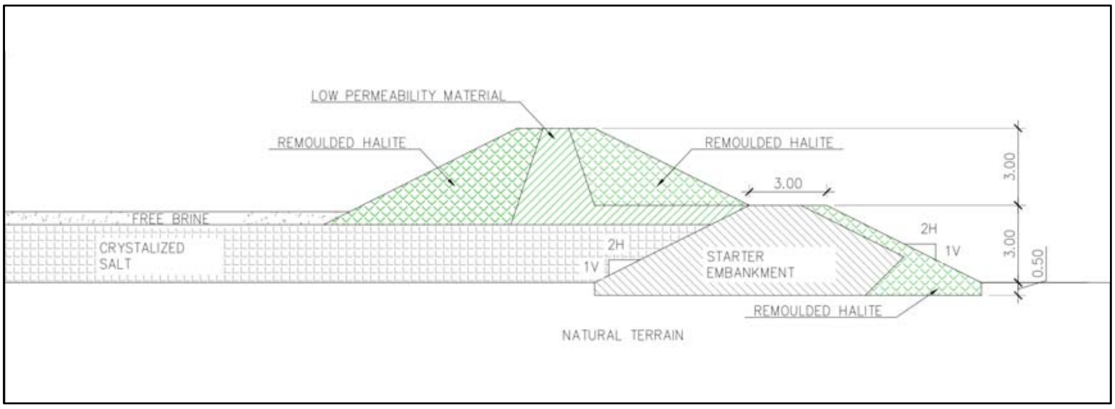

Figure 6. Typical cross section of a evaporation pond-salt stack for a project in the lithium triangle – internal database, SRK.

Finally, distance to, and difference in elevation from, the process plant will affect the sizing of the disposal pipelines and energy consumption.

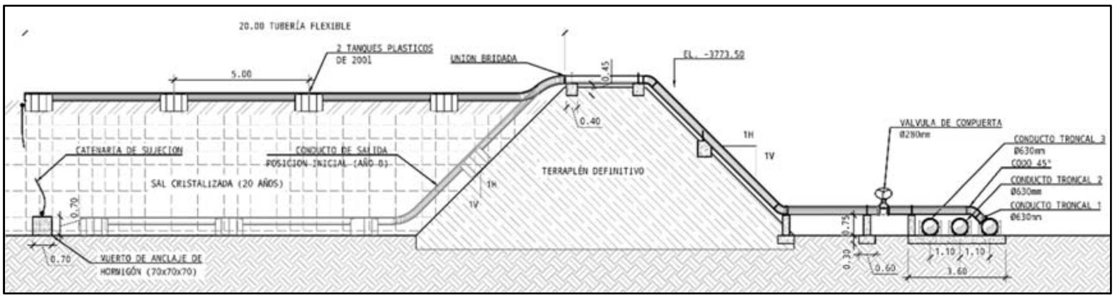

Figure 7. Typical cross-section of the starter embankment on the disposal spine side of a facility.

5 CONCLUSIONS

Lithium mining from highly enriched brines is significantly different to classic hard-rock mining, given the fluid nature of the resource host (i.e. the brine). As so, mineral extraction from shallow brines presents issues related to the fluid nature of the resource host, with the resource in solution, such as the potential for composition and grade temporal variation, before and during extraction.

Given the nature of this type of project, brine resource and reserve estimation requires the application of specialised hydrogeological knowledge, i.e. hypersaline solution theories for groundwater dynamics modelling, and chemical processing engineering, i.e. brine processing for high-purity Li2CO3 extraction.

Direct extraction technologies arise as an alternative to the conventional production processes. The conventional process is based on increasing the concentration of lithium through solar evaporation in evaporation ponds. Among the advantages of direct extraction processes are: a shorter period between extraction commencing and the first lithium carbonate (Li2CO3) batch being produced (almost immediate), lower capital costs and reduced dependence on climate.

Direct extraction processes can generate large amounts of spent brine (i.e. brine with a reduced lithium concentration), which may potentially affect the lithium-rich brine concentration. In order to retain the advantages of direct extraction processes, management of spent brine tailings requires adequate planning and diligent engineering to be undertaken. It is key to achieving a cost-efficient disposal solution to undertake a holistic approach in terms of balancing evaporation, crystallisation and seepage to keep the recycled brine inflow to the basin at a controlled rate (and potentially at an increased mineral concentration – similar to the raw brine concentration)

This presentation has compared alternative disposal solutions, and showcases some recent experience with spent brine tailings management at projects in the lithium triangle of South America.

The specific details and concepts of brine lithium mining projects, can be applied to a wide variety of brine projects, i.e. both conventional evaporation and direct extraction processes for lithium (Li), potassium (K), boron (Bo), sulphate (SO4-2) and others.

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