Guidelines for Resource and Reserve Estimation for Brines

Mineral-enriched brines contain valuable elements in solution that may be economically recovered. Such brines can be found in aquifers beneath closed drainage basins and paleochannels in arid environments, such as below salt lakes and salars or playas, where high rates of evaporation concentrate the brine.

A brine deposit is hosted by one or more aquifers (hydrogeological units that contribute to brine flow and storage), that may be under confined, semi-confined or unconfined conditions and may be separated by aquitards (hydrogeological units that contribute only to brine storage). Evaluation of brine abstraction will involve assessment of the interaction between aquifers and aquitards.

Evaluation of brine mineralisation requires an understanding of the basin hydrogeology, geological continuity and the hydraulic parameters of the host aquifers. Unlike solid minerals, the valuable elements are mobile as they are dissolved in the brine. An important distinction from hard rock mineralisation is that during abstraction, brine composition and grade have a temporal component, because of groundwater flow, potential mixing between, and recharge of, aquifers. This temporal component requires consideration by the Competent Person(s) during the conversion of Mineral Resources to Ore Reserves.

The provisions of the JORC Code apply to the Public Reporting of Exploration Results, Mineral Resources and Ore Reserves that involve brines. This guideline is intended to describe the unique technical considerations that are required to report brine mineralisation, Resources and Reserves in relation to the JORC code.

Hydrogeological Setting

A description of the hydrogeology of a brine deposit requires consideration of hydrological aspects of the deposit, such as surface water and groundwater fluxes, water balance and geology of the aquifer system along with the dimensions and composition of the brine deposit.

In addition, an understanding of the hydrogeology and the water balance of the broader groundwater system that hosts the brine-deposit is required for the proper evaluation of a brine deposit. The brine chemistry is affected by groundwater and surface water inflow from the catchment, the different geological units present in the catchment, possible contributions from springs and by the evaporation and precipitation conditions.

All of this is analogous to obligations for reporting of grade and geological continuity of hard rock mineralisation under Clause 20 of the JORC Code.

Temporal and Spatial Effects

When brine is abstracted from an aquifer, the conditions become dynamic in response to pumping. Over the life of a brine mining operation, rainfall-recharge may replenish a brine aquifer with fresh water, diluting the concentration of elements of interest and / or remobilising otherwise immobile brine contained in specific retention. The Competent Person(s) should understand these dynamic relationships and provide an analysis of their effect for the purposes of Ore Reserve estimation and evaluation of brine abstraction.

The assessment of the basin hydrology and water balance will require the consideration of meteorological parameters over time and this information should be collected during evaluation of a brine project.

Brine aquifers can be of considerable size and several operators may abstract from the same aquifer. Property rights in brine deposits are defined by nominally vertical planes between surface coordinates. However, due to the dynamic nature of the aquifers, brine abstraction operations can have effects beyond the corresponding property limits. Simulation of the hydrogeological conditions in a groundwater model can be used to predict the effect of abstraction from beyond the property where pumping is conducted.

Clause 4 of the JORC Code (*Materiality*) obliges the Competent Person(s)(s) to understand and report on the potential impact of abstraction at adjacent properties. Ore Reserve estimation should consider property boundaries. (Any supporting groundwater model may provide a tool for evaluating management scenarios with neighbouring parties).

All of this is analogous to obligations for reporting of the mining, processing and metallurgical Modifying Factors and reporting of losses and dilution for hard rock mineralisation under Clause 29 of the JORC Code.

Estimating Aquifer Parameters

Definition of the aquifer characteristics of sediments that host brine is an essential part of exploration programs and the subsequent estimation of Mineral Resources and Reserves. The Competent Person(s) must take care to ensure estimates of aquifer parameters are representative.

The Competent Person(s) should determine and explain those aquifer parameters that are relevant for a specific brine-deposit and specific stage of evaluation and-provide adequate detail on the method(s) used to determine each parameter. Explanation should extend to parameters that control recharge and remineralisation / dilution where recharge forms a material component of the specific brine-evaluation.

Methods may include (but are not limited to) geophysical techniques that are capable of measuring porosity, specific yield and permeability in-situ, laboratory porosity and permeability analyses on core samples, derivations from pumping tests and estimation from particle size distribution analysis.

It is preferable that specific yield and hydraulic conductivity estimates be verified by independent methodologies and multiple pumping tests and the Competent Person(s) should provide comment on the level of confidence and range in the estimate of each parameter based on the comparison of methodologies.

Definitions of key aquifer parameters are provided below:

- **Specific Yield (Sy)**: volume of fluid obtained under gravity-flow conditions from a unit volume of aquifer material.
- **Specific Retention (Sr)**: volume of fluid retained under gravity drainage, in volume of aquifer.
- **Total Porosity (Pt)**: total volume of pores, saturated with brine, within a unit volume of aquifer. The Total Porosity may be substantially larger that the Specific Yield and includes brine that cannot be abstracted. Consequently, use of Total Porosity in Mineral Resource Estimates can be misleading and should not be presented in public documentation unless the Competent Person(s) can justify why it is necessary to provide this information.
- **Storativity (S**): a function of fluid and aquifer compressibility that provides a measure of the brine released per unit reduction in pressure in a confined aquifer.
- **Horizontal hydraulic conductivity (Kh):** a measure of the ability of a material to horizontally transmit a fluid when subjected to a hydraulic gradient. Horizontal hydraulic conductivity will affect the potential to abstract brine from the aquifer.

• **Vertical hydraulic conductivity (Kv):** a measure of the ability of a material to transmit a fluid vertically when subjected to a hydraulic gradient. Vertical hydraulic conductivity will affect the vertical movement of brine between aquifers or between aquifers and aquitards.
• **Transmissivity (T):** a measure of the rate of horizontal flow through a unit width of aquifer per unit gradient. An aquifer may consist of multiple layers with different transmissivities in the horizontal and vertical dimensions. These differences should be considered because transmissivity will affect the abstraction of brine from the aquifer. Transmissivity is a function of horizontal hydraulic conductivity and aquifer thickness.
• **Diffusivity/dispersivity**: these parameters influence the mixing of groundwater and pore-water within the brine-aquifer system.

Brine Chemistry and Sampling
Brine chemistry has a direct and significant impact on the economic potential of a brine deposit and requires representative brine samples; an understanding of the lateral and vertical distribution of the elements of interest and an understanding of the chemical components of the brine and how this will change during evaporative concentration and mineral processing.
Brine chemistry shows lateral and vertical variations and it is necessary to have enough sample points within the different sedimentary environments to support Mineral Resource and Ore Reserve modelling. Brine continuity is likely to change in some environments (for example the margins of a deposit or where groundwater inflow to a deposit occurs) more than others (the centre of a deposit). This information should be considered when developing Mineral Resource estimates. Appropriate commentary is obliged under Table 1, Sections 1, 2 and 3 of the JORC Code.

Brine Chemical Evolution and Processing
Clause 20, "*reasonable prospects*", of the JORC Code obliges that Competent Person(s) to understand and report on the relationships between the various cations and anions that effect brine processing, operating costs and recovery of the elements of interest. Concentrations of deleterious elements and elements of interest typical vary laterally across a brine deposit.

For the purpose of Ore Reserve estimation, Clauses 29 and 32 of the JORC Code oblige that the Competent Person(s) understands and reports on the predicted changes in brine chemistry over time due to both inflows into the aquifer system from the surrounding catchment, recharge and as a result of the response to abstraction from the brine body. This is important as the brine concentration can vary with time, depending on abstraction methods, pumping rates and inflows from adjacent aquifers.

Reporting of Exploration Results and Mineral Resource Estimates
The principal porosity measurement for brine Mineral Resource Estimate is the specific yield (Sy). The Competent Person(s) should provide justification for the reporting and use of other measures of porosity. The incorrect or inappropriate use of porosity may result in a material over-estimate of potentially recoverable brine. The Competent Person(s) should be conscious of this and present the uncertainties associated with porosity measurements in public reports containing the Mineral Resource estimate.

Mineral Resource Estimates for brines should generally be estimates of the brine volume under static conditions. Temporal effects such as mixing, and recharge are uncertain in time and dependent on a chosen abstraction plan. As such, they are better considered as Modifying Factors and the Competent Person(s) should provide explanation where they have been included in Resource estimations.

Mineral Resource estimation for brines should involve:

- Determination of the Specific Yield (Sy) of the brine-aquifer.
- Definition of the brine-aquifer geometry.
- Determination of the concentration of the elements of interest.
- Determination of appropriate boundaries for the Mineral Resource Estimate.

The brine aquifer geometry is a function of the shape of the aquifer, its internal structure and its boundary conditions as they affect possible interactions between the brine and the surrounding groundwater. Aquifer geometry and boundary conditions can be established by drilling and geophysical methods.

The Competent Person(s) should describe the basis for the boundary of the Mineral Resource Estimate. Due to temporal changes in grade during abstraction, a cut-off grade may not be appropriate for the static brine deposit and other options may include property boundaries (where the brine aquifer is more extensive) or aquifer boundaries (where there are marked changes in aquifer properties within the brine deposit or where the edge of an aquifer marks the edge of brine mineralisation).

Physical evidence will be required to estimate the aquifer lithology, hydrostratigraphy, porosity, hydraulic conductivity, specific yield and lateral and vertical brine-grade variations. Aquifer parameters vary, and site-specific estimates should be generated for any level of assessment. The selection of drilling methods, drill hole spacing, and drilling depths is the responsibility of the Competent Person(s). In developing the drilling and sampling program, the Competent Person(s) should consider:

- The drilling technique(s) should be conducive to recovery of appropriate representative samples for the evaluation of multiple parameters including determination of aquifer porosity, permeability and brine chemistry
- determination of specific yield (Sy);
- Brine-sample intervals should support Mineral Resource estimation and be designed around observed changes in stratigraphy, at the time of drilling; and
- Brine-sampling protocols should accurately determine the in-situ location of the sampled intervals.

Estimates of aquifer hydraulic conductivity and aquifer transmissivity do not generally form part of the Mineral Resource Estimate. However, Clause 20, "*reasonable prospects*", of the JORC Code obliges that Competent Person(s) to have regard to the potential for future brine abstraction.

Reporting of Brine Ore Reserves

Technical and Metallurgical Modifying Factors specific to brines are those that influence the dynamic behaviour of the brine system and include hydraulic conductivity and transmissivity, storativity, rainfall-recharge, dispersity/ diffusivity and mixing with other groundwater bodies.

Assumed values for key parameters should generally be unacceptable at an Ore Reserve assessment level. The exception is dispersivity/diffusivity, for which the Competent Person(s) may determine empirical methods of estimation can be used; in this event the Competent Person(s) should provide comment.

Information is also required on the efficiency of the abstraction system. The Competent Person(s) should consider and comment on the brine aquifer water balance with respect to the land-tenure

from which brine will be abstracted and the broader catchment area. The Competent Person(s) should also comment on the characteristics of the margins of the brine body (where the density of the fluid changes relatively rapidly) and the characteristics of the surrounding bedrock and rainfall-recharge conditions. These factors will influence the concentration of elements in the brine (over time) and the hydrostatic pressure of the brine aquifer and they may result in dilution.

In the case of brine projects, the abstraction scheme is the equivalent of a mine plan. The scheme should describe the location, depth, spacing and pumping rate of drainage trench and bore infrastructure. A brine Ore Reserve estimate should be based on the defined brine volume and concentration that will be produced for a defined period and a specific abstraction scheme. The concentration of produced brine may change over time, as leakage, mixing and rainfall-recharge occurs within the aquifer. The rate of change will be dependent on the stress placed on the hydrogeological system by the abstraction and will be a function of hydrogeology, time, scheme design and pumping rate. Cut-off grade should be considered in this context and based on pumping test information and chemical processing criteria (based on detailed process flow sheets) rather than an in-situ brine concentration or grade-shell.

Numerical groundwater flow models are essential for production and grade forecasts to be made and their limitations and uncertainty should be described when outlining the results of Ore Reserve estimation and determination of a production schedule.

Brine Mineral Resources and Ore Reserves should be reported as a volume of brine and concentration for the valuable elements and the equivalent tonnes of mineral(s) of interest. Conversion factors used for the reporting of mineral-compounds must be clearly stated

Acknowledgements
This document draws on the **CIM Best Practice Guidelines for Resource and Reserve Estimation for Lithium Brines**, and the subsequent 10-years of their use, so that there is both international continuity and continuous improvement in approach.