VARIABLE - DENSITY BRINE DEPOSITS: GROUNDWATER MODELLING AND IMPLICATIONS

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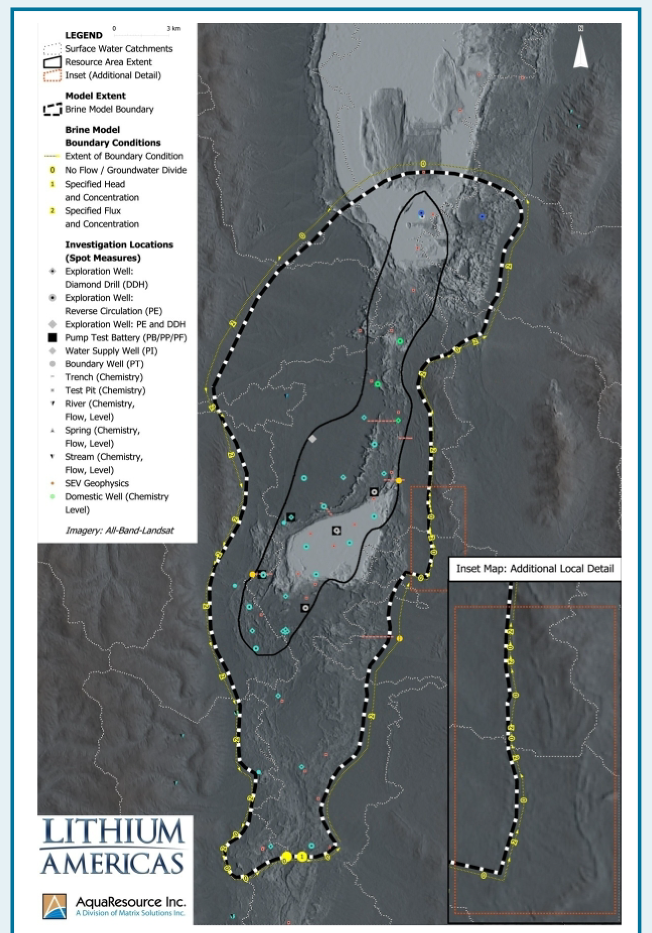
Introduction

The Cauchari and Olaroz salars in northern Argentina (Figure 1) contain dense, subsurface brines that are rich in lithium (Li) and potassium (K). Lithium Americas Corporation (LAC) intends to extract these brines to produce potassium chloride and lithium carbonate salts through an evaporative process. Lithium carbonate can then be used in the production of lithium-ion batteries.

1. Regional map and site location

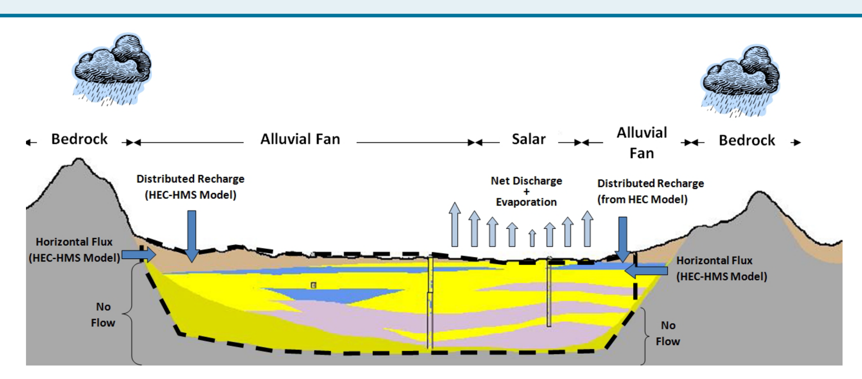
Regional Groundwater Model



2. Regional groundwater flow model domain

A companion presentation at the IAH 2012 Congress (Anderson et al.) describes the development of a detailed three-dimensional groundwater flow that was developed by AquaResource using FEFLOW.

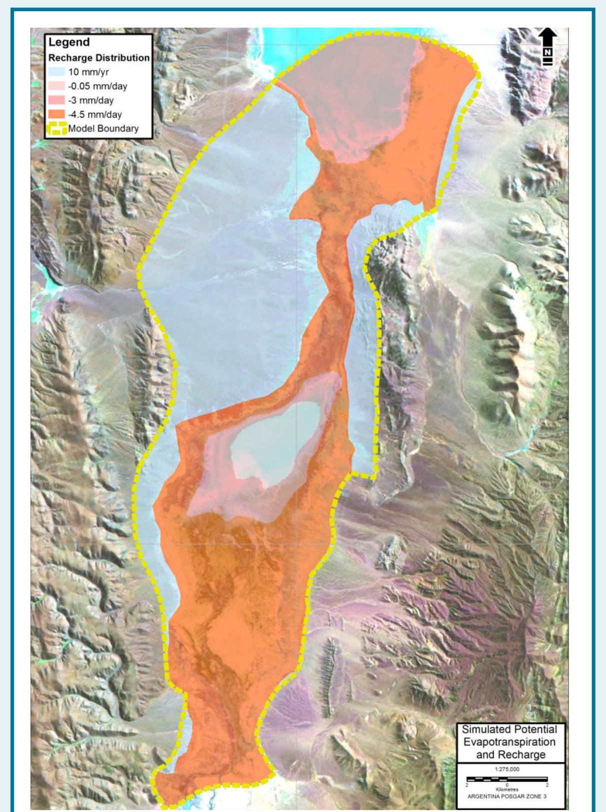
Figure 2 shows the extent of this regional model. The resource area is shown as a thin black line, and the model domain is outlined by a thicker dashed black line.



3. Conceptual west-east cross section through the regional model domain

Figure 3 shows a West-East cross section through the model domain. The Olaroz-Cauchari basin consists of alluvial fan deposits of silt, clay, sand and salt (halite). The hydrogeologic characterization was interpreted from borehole, geophysical and hydraulic test data and is discussed in further detail by Weaver et al., (IAH 2012 Congress).

Also shown in Figure 3 is a conceptual water balance. Fresh water enters the basin as recharge in the form of either horizontal flux from the mountain ranges, or from distributed recharge along the alluvial fan at ground surface. Water exits the basin by evaporation along the ground surface of the salar.

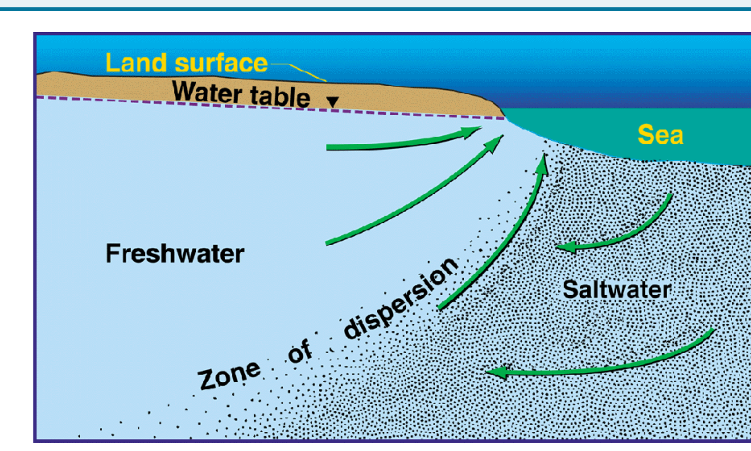


4. Distribution of recharge/discharge boundary conditions

Figure 4 shows the distribution of recharge and discharge in the regional groundwater model. Note that discharge is highest along the salar boundaries, which can be seen at the site, where precipitated salts are present at surface.

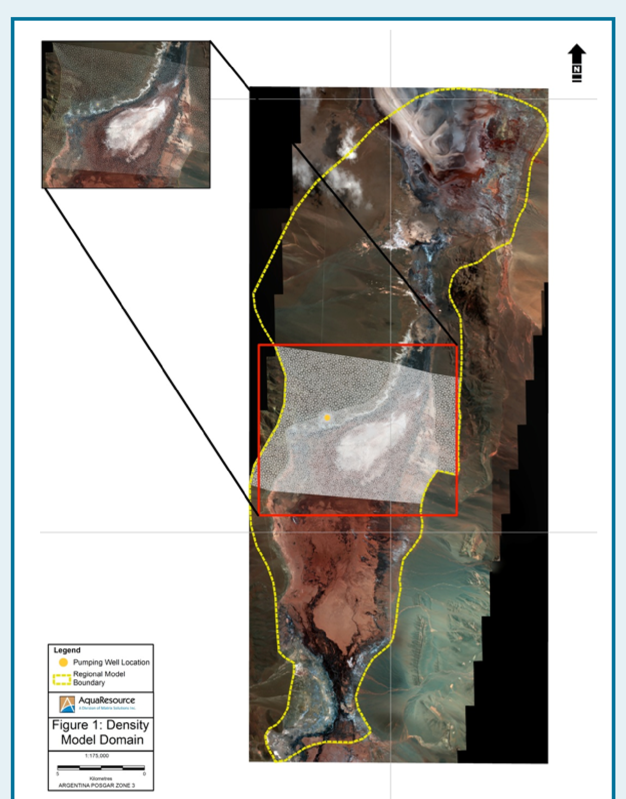
Density Dependent Groundwater Modelling

In groundwater systems where water density has the potential to play a significant role, groundwater flow can occur as two processes: (1) advection – flow of water from high hydraulic head to low hydraulic head and (2) convection – flow of water due to density gradients. The significance of density-induced flow in a given setting depends on a range of physical features, including the distribution of the dense groundwater, hydrostratigraphic layering, hydraulic conductivity distribution, porosity, anisotropy, boundary conditions and initial conditions.



5. Conceptual example of saltwater intrusion

Figure 5 shows a typical example of saltwater intrusion, where denser salt water from the sea flows beneath less-dense freshwater.
Within the Cauchari salar, groundwater sampling has shown that concentrations of Total Dissolved Solids (TDS) reach values of over 300,000 mg/L. This results in a water density of approximately 1.2 times greater than fresh water.

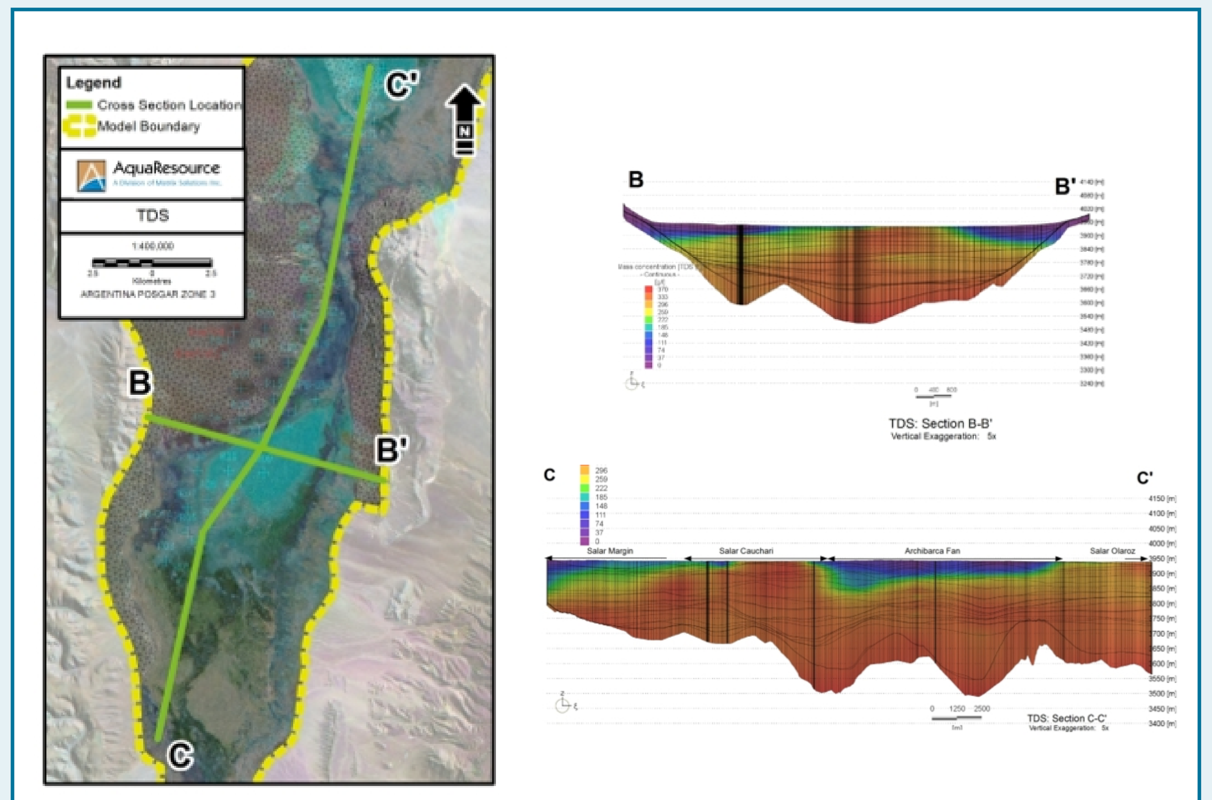


6. Regional Model domain and Density Model domain

In order to examine the effects of density-induced flow, a smaller model domain has been set with a single extraction well. This model (referred to here as the "Density Model") consists of a portion of the larger Regional Model of the site that includes most of the Cauchari salar and the southern portion of Archibarca fan (Figure 6 left). The three-dimensional (3D) modelling domain used for both the Regional and Density Models is shown in Figure 6.

Initial Conditions - Brine Distribution

For the Regional Model, initial conditions were set up for concentrations of Total Dissolved Solids (TDS) based on a 3D interpolation of the chemistry data. Different tools (i.e., LeapFrog, VIEWLOG) were used to interpolate the chemistry data in 3D. As such, the results used in the Density Model were the interpolated concentrations (of TDS) that were available at the time.



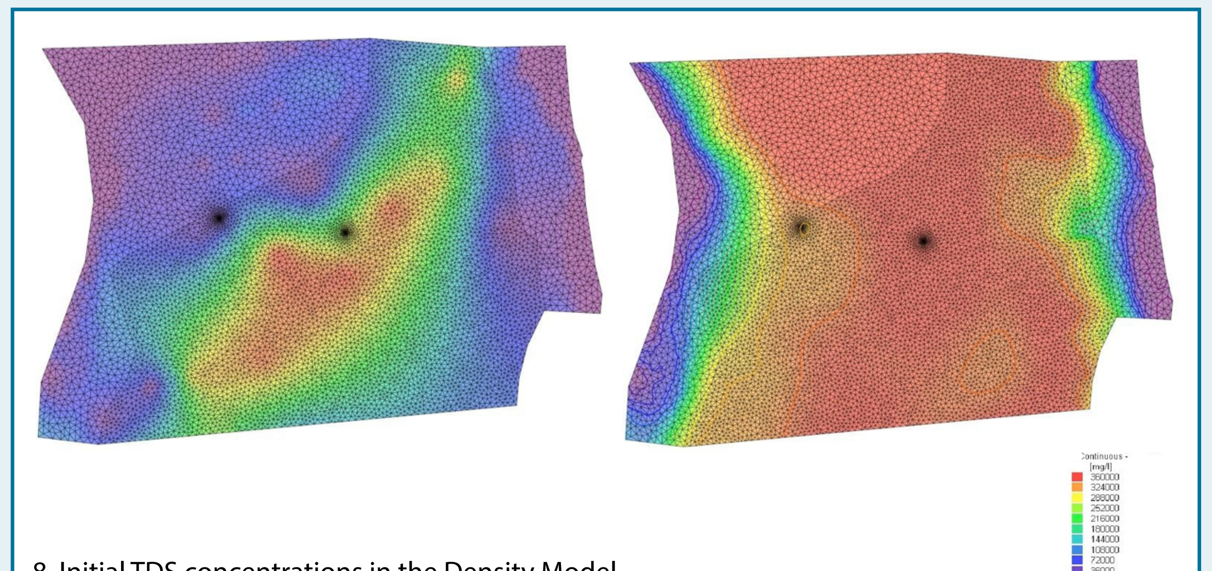
7. TDS contours in W-E, and S-N cross sections

Figure 7 shows the TDS contours along two cross sections within the Regional Model, B-B' (West – East) and C-C' (South – North).

As expected, higher TDS concentrations (and higher-density groundwater) is present at depth, with lower concentrations closer to the ground surface.

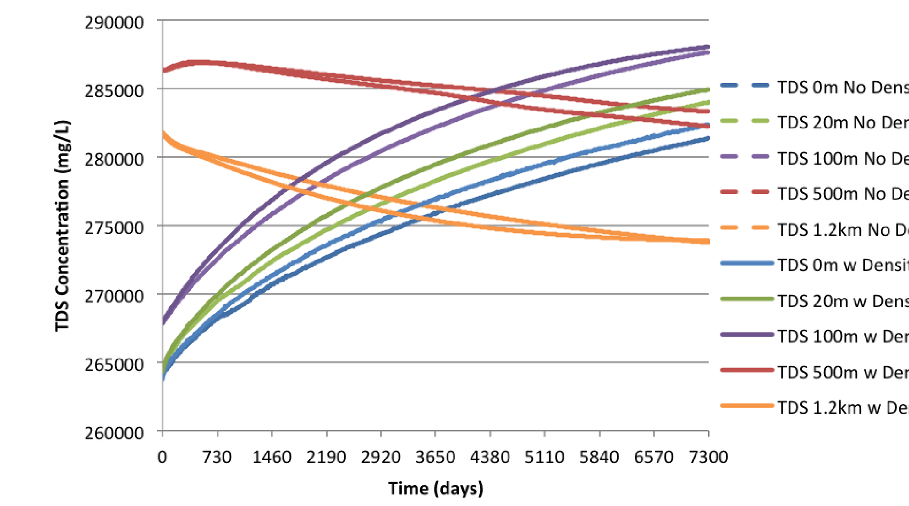
Numerical Simulations

The initial concentrations in the Density Model were based on TDS distribution as show previously. Figures 8 a, b shows the initial TDS concentrations along two plan-view model slice layers – (a) near the top of the model, and (b) near the bottom of the model.



8. Initial TDS concentrations in the Density Model

A single extraction well was added to this model and simulations were run for 20 years. Concentrations were examined at the extraction well and at nearby observation locations. This comparison formed the basis for evaluating whether density-induced groundwater flow plays a significant role in a typical pumping scenario at the site.



9. Model results – Comparison of Density versus Non Density Simulations.

Figure 9 shows concentrations at the five observation locations for simulations that include density-induced flow (solid lines) and those that do not (dashed lines).

The main observation from this simulation is that concentrations are relatively insensitive to the inclusion of density-induced flow. This observation shows that in this setting density-induced groundwater flow does not play a significant role in the transport of solute.

Summary and Conclusions

A Density Model has been set up to examine the effects of density-induced groundwater flow at the Cauchari salar in Argentina. To examine the effects of density-induced flow, we compared two simulations: one that included density-induced flow and a second that did not.

Examination of model results shows that concentrations at the extraction well and the observation locations do not differ significantly. This indicates that density-induced flow does not have a significant influence on the composition of brine recovered from the extraction well.

The possible reasons for this are:

- **Hydraulic conductivity (K) variation:** The 24 model layers have different values of K, and within some layers K can vary. These heterogeneities can inhibit density-induced flow of groundwater between layers.
- **Anisotropy:** Each K zone has an anisotropy value that can range from 10 to 10,000. This implies that the vertical component of hydraulic conductivity (Kz) is 1 to 4 orders of magnitude lower than the horizontal components (Kx, Ky). This acts to further inhibit density-induced flow.
- **Initial conditions:** The initial distribution of TDS is likely near steady-state, with higher concentrations (and higher densities) at depth and fresher water (with lower concentrations and densities) closer to ground surface. Density-induced flow plays a more important role when a more dense fluid overlies a less-dense fluid.

While it is noted that the inclusion of density-induced flow has a minimal effect on the simulation results, it is also noted that the minimal effect is positive at the pumping well. In this sense, the exclusion of density from the model adds a slight degree of conservatism (i.e., under-prediction) to the simulation of brine recovery.

Based on these results, it is concluded that the time required for breakthrough of less dense water from the boundaries of the salar to an extraction well within the salar is not significantly influenced by density-induced flow. It is noted that this conclusion is site-specific, and may not be applicable for other salar settings, especially those with less heterogeneity and layering contrasts.

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