# Aggregation of Resources in the Context of $CO_2$ Geosequestration

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## BACKGROUND

Carbon dioxide ($CO_2$) sequestration in the subsurface is widely recognized as one important approach to mitigate global climate change, yet practical implementation is at its infancy. As a first step of a technologically complex and economically expensive initiative, the U.S. Geological Survey is at the concluding stages of a probabilistic assessment to evaluate the capacities and uncertainties across the country for an potential systematic implementation of $CO_2$ geosequestration away from fresh groundwater aquifers (Brennan et al., 2010). Additionally, injection depth has been restricted primarily to formations in the 914−3962 m range to reflect technological feasibility.

Pore space calculations have been conducted using volumetric methods. Mechanisms for retaining $CO_2$ in the subsurface at a supercritical state are: (a) buoyant trapping and (b) residual trapping. Buoyant trapping is restricted to geologically closed structures. Everywhere else, the trapping is considered to be of the residual type and is subdivided into three efficiency categories depending on reservoir permeability. Given the size of the total area to assess, the country has been subdivided into approximately 200 storage assessment units (SAUs). Therefore, using the Monte Carlo method, results for each SAU consist of probability distributions for 5 categories of trapping capacity converted to subsurface mass: buoyant, three types of residual, plus total tonnage. This presentation focuses on the challenge of adding the partial results per SAU to the basin, region and country level for inference of resources and their associated uncertainties.

## PRACTICAL CONSIDERATIONS

The norm is scarcity of hard data to be able to calculate the exact degree of association in the storage capacity of pairs of SAUs. The correlation coefficients are thus inferred using approaches typical of elicitation of expert judgment and Bayesian statistics.

When, like in our case, there is interest in partial aggregations, aggregations for successive stages can be done in two ways: (a) always starting from individual SAUs (single stage); and (b) using the partial aggregations over smaller areas to obtained results for larger areas (multi-stage). Multi-stage aggregation has the advantage of requiring the definition of significantly less correlations coefficients.

Our research produced two important findings: (a) when using the same correlation coefficient for all SAUs in two different regions such as regions A and B in Figure 1b in a single-stage aggregation and the same value also for the corresponding region-to-region correlation coefficient in a multi-stage aggregation, the probability distribution for the multi-stage aggregation has less dispersion than the one for single-stage aggregation. The discrepancy is more significant as the number of SAUs and stages increases. One way to obtain comparable distributions is to have region-to-region coefficients larger than those between the corresponding SAUs, which is counterintuitive. (b) Figure 2 shows that the sensitivity of the aggregation to specific values of the off diagonal correlation coefficients decreases as the number of individual SAUs increases, thus making less critical the inference of correlation coefficients in single-stage aggregation.

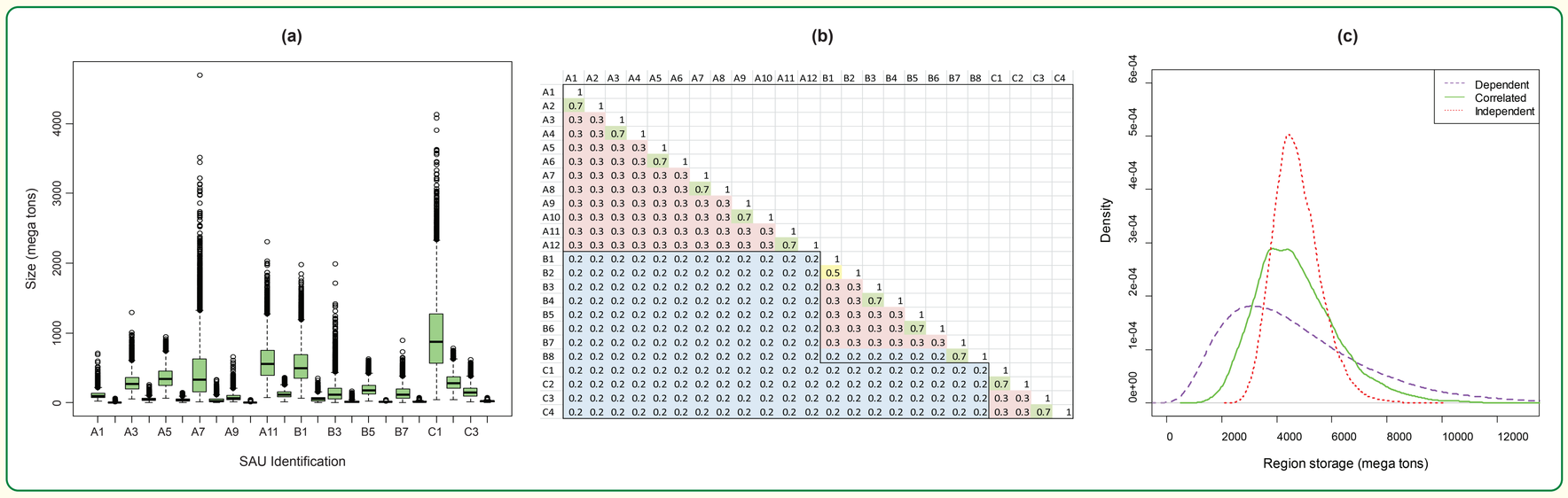


**Figure 1.** Example of aggregation of 24 SAUs grouped into three regions A, B and C: (a) SAU probability distributions; (b) correlation matrix; (c) aggregation, including additional extreme cases of total independence and perfect correlation.

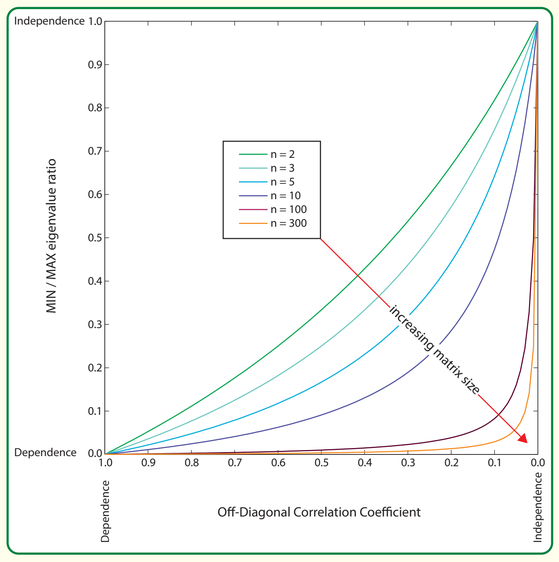


**Figure 2.** Relationships among number of SAUs, value of the off-diagonal elements when all of them are equal, and measure of overall dependency as the minimum to maximum eigenvalue ratio.

## METHOD

There are two main inputs in the aggregation. The first is the stochastic estimates of $CO_2$ storage capacity at subsurface conditions for each SAU in the form of numerical probability distributions accounting for uncertainty (e.g. Figure 1a). The estimated capacity was obtained by 10,000 Monte Carlo simulation runs for each of the four itemized storage categories. For convenience, the simulation ignores any correlations that may exist among the SAUs. The second major input is a correlation matrix specifying the ignored dependency between SAUs (e.g. Figure 1b). The Cholesky decomposition is used to aggregate SAUs imposing these correlations, thus compensating for the simplification in generating the probability distributions independently.

The result of aggregating several probability distributions is another distribution. Figure 1c illustrates 3 possibilities: (a) assuming perfect dependence, which implies a matrix full of 1s; (b) partial dependence specified in this case by the matrix in Figure 1b; (c) total independence, where all off-diagonal elements in the matrix are zero. As dependency increases, so does uncertainty.

## CONCLUSIONS

Aggregation matters and presents some subtleties. If there is interest in partial aggregations, beyond the first level, further aggregations can be obtained always starting from either individual SAUs or building on previous results. We favor single-stage aggregation because: (a) it is easier for the assessors to infer correlation coefficients between SAUs than, say, between basins; (b) use of, say, basin-to-basin correlation coefficients in multi-stage aggregation equal to the correlation coefficient between SAUs in these basins results in less uncertainty than single-stage assessments; (c) as the number of SAUs increases, single-stage aggregation is less sensitive to errors in the correlation coefficients.

## REFERENCE

Brennan, S.T., Burruss, R.C., Merrill, M.D., Freeman, P.A., Ruppert, L.F., 2010. A probabilistic assessment methodology for the evaluation of geologic carbon dioxide storage. U.S. Geological Survey Open File Report 2010-1127, http://pubs.usgs.gov/of/2010/1127/ofr2010-1127.pdf.

U.S. Department of the Interior
U.S. Geological Survey

August, 2012