LA-UR-11-12136
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Intended for:
DOE
AGU Fall Meeting, 2011-12-03/2011-12-09 (San Francisco, California, United States)
Groundwater
Reading Room
RCRA



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Uncertainty Quantification of the Leaked CO_2 from Deep Reservoirs to Shallow Groundwater

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H13B-1210

1. Introduction and Motivation

One of the areas of concerns for geologic CO_2 sequestration is the potential of leakage of CO_2 as well as deeper brines from deeper storage reservoirs to shallow groundwater resources. This could lead to changes in groundwater chemistry. As part of the National Risk Assessment Partnership (NRAP) for geologic CO_2 sequestration project, we use the Edwards aquifer as an example to perform modeling studies for understanding the mechanisms of the leaked CO_2 flow, transport and reaction with aquifer water and minerals. The goal of these studies is to capture the complex multi-phase flow and multi-component reactive transport processes and the effect of uncertain parameters in the form of a response surface.

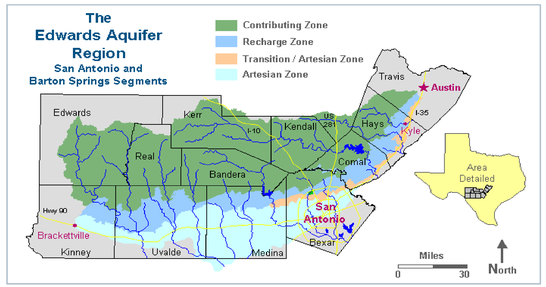


Fig. 1: The distribution of the Edwards Aquifer (modified from Gregg Eckhardt's website)

2. Model domain and boundary conditions

We have developed a 3-dimensional heterogeneous numerical model for an un-confined shallow aquifer that is being used to simulate the CO_2 leakage and the associated geochemical interactions over 200 years.

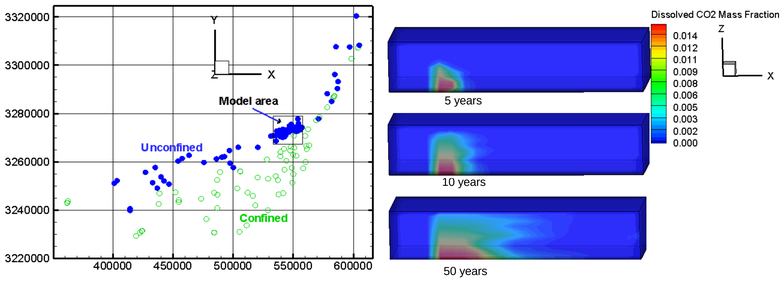


Fig. 2: Locations of the model area in the Edwards Aquifer (left) and the simulated CO_2 plumes at different time from one of the 500 realizations (right). The model dimension is 19kmx23kmx150m.

Table 1: The distributions of the nine uncertainty parameters

	Parameter	Symbol	Min.	Max.
Aquifer	Permeability sill	sill	0.01	0.9
	Integral range (m)	range	1500	10000
	Anisotropic factor	Fkxz	1.00	100
	Lateral flow rate (kg/s)	flowr	2.65	131
Leakage source function	Max leakage rate (kg/s)	q0	0.055	0.5
	Dis to injection well(m)	dis	10	4300
	Injection Time(yr)	injT	40	150
	Vk (related to velocity)	vk	0.5	5.0
	Constant	a0	0.1	1.0

Abstract: The response surface approach is used to derive the reduced order models in a quantitative risk assessment framework for developing risk profiles related to CO_2 leakage. We perform a Monte-Carlo analysis to estimate the probability and plume sizes of the pH below 6.5 and TDS > 500ppm in the shallow aquifer while taking into account the reactions of CO_2 with the chemical components and the major minerals. A global sensitivity analysis is conducted for 15 outputs (the amount of CO_2 leaving the top of aquifer, the plume sizes and locations of the pH below 6.5 and TDS > 500 ppm, with the MARS screen method and Delta-Test method using PSUADE (Tong, 2011). Finally, we present the one-, two- and three-dimensional response surfaces developed based on the 500 forward modeling results of the reactive transport models.

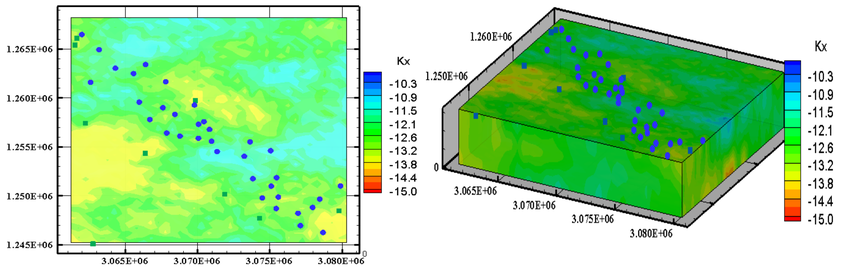


Fig. 3: The distribution of heterogeneous permeability fields in two- (left) and three-dimensional view (right).

3. Uncertain parameters and leakage source functions

There are 9 uncertain parameters in our study including three for describing geologic heterogeneity in the permeability (sill, integral range, anisotropic factor), a lateral groundwater flow rate and five parameters to characterize the leakage source functions for CO_2 and Brine.

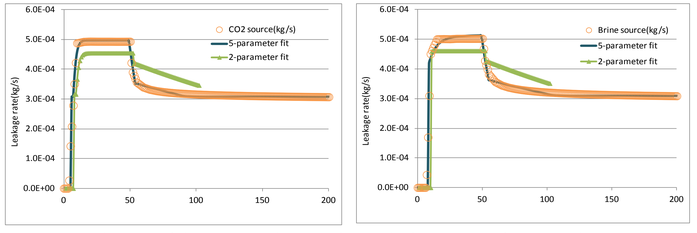


Fig. 4: One realization of the computed CO_2 and Brine leakage source functions during 200 years.

4. Global sensitivity analysis

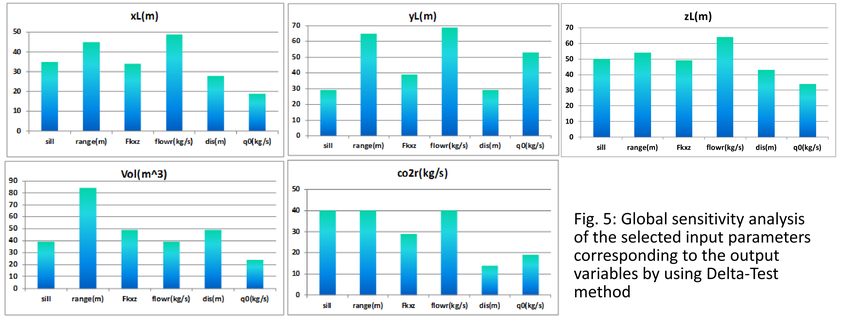


Fig. 5: Global sensitivity analysis of the selected input parameters corresponding to the output variables by using Delta-Test method

5. Response surface analysis

When the lateral flow rate increases, the plume volume and size decrease, on the other hand, when the maximum CO_2 leakage rate increases, the plume volume and size increase because more CO_2 leaks into the shallow aquifer. The TDS > 500 ppm plume volume and size increase with time.

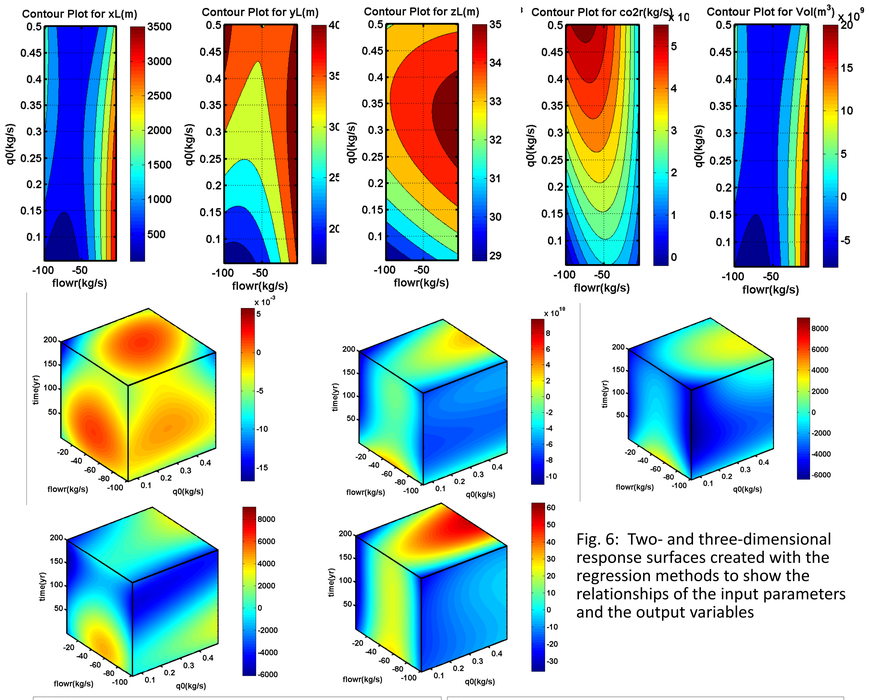


Fig. 6: Two- and three-dimensional response surfaces created with the regression methods to show the relationships of the input parameters and the output variables

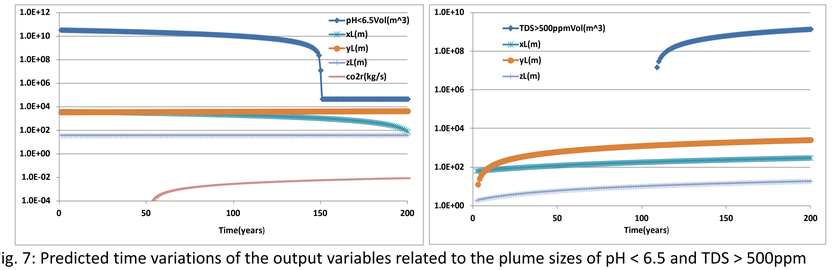


Fig. 7: Predicted time variations of the output variables related to the plume sizes of pH < 6.5 and TDS > 500ppm by using developed response surface functions.

6. Conclusions and Future Researches

- The global sensitivity analysis indicates that the lateral flow rate is one of the most sensitive parameters, and the CO_2 and TDS plume sizes are also very sensitive to the scale of permeability, the distance to the injection well and the maximum leakage rate.
- The CO_2 (pH<6.5) plume volume and sizes (in x,y,z directions) decrease with time, while the CO_2 leakage rate from the water table increase from 50 to 200 years.
- The TDS>500 ppm plume volume and sizes increase with time, because the brine (Cl and Na) accumulates in the shallow aquifer due to the leakage of CO_2 and brine from deep reservoirs.
- Future research will focus on characterizing multiple leakage sources and aquifer heterogeneities.

Acknowledgement: This work is funded by the DOE NRAP Project at LANL. Related CO_2 presentations in this AGU meeting include: H23B-1247 by Viswanathan, H32B-07 by Keating, GC51A-0945 by Jordan, H54D-06 by Bacon and GC51A-0945 by Pawar.