Enhanced Analytical Simulation Tool for CO_2 Storage Capacity Estimation

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U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Transforming Technology through Integration and Collaboration

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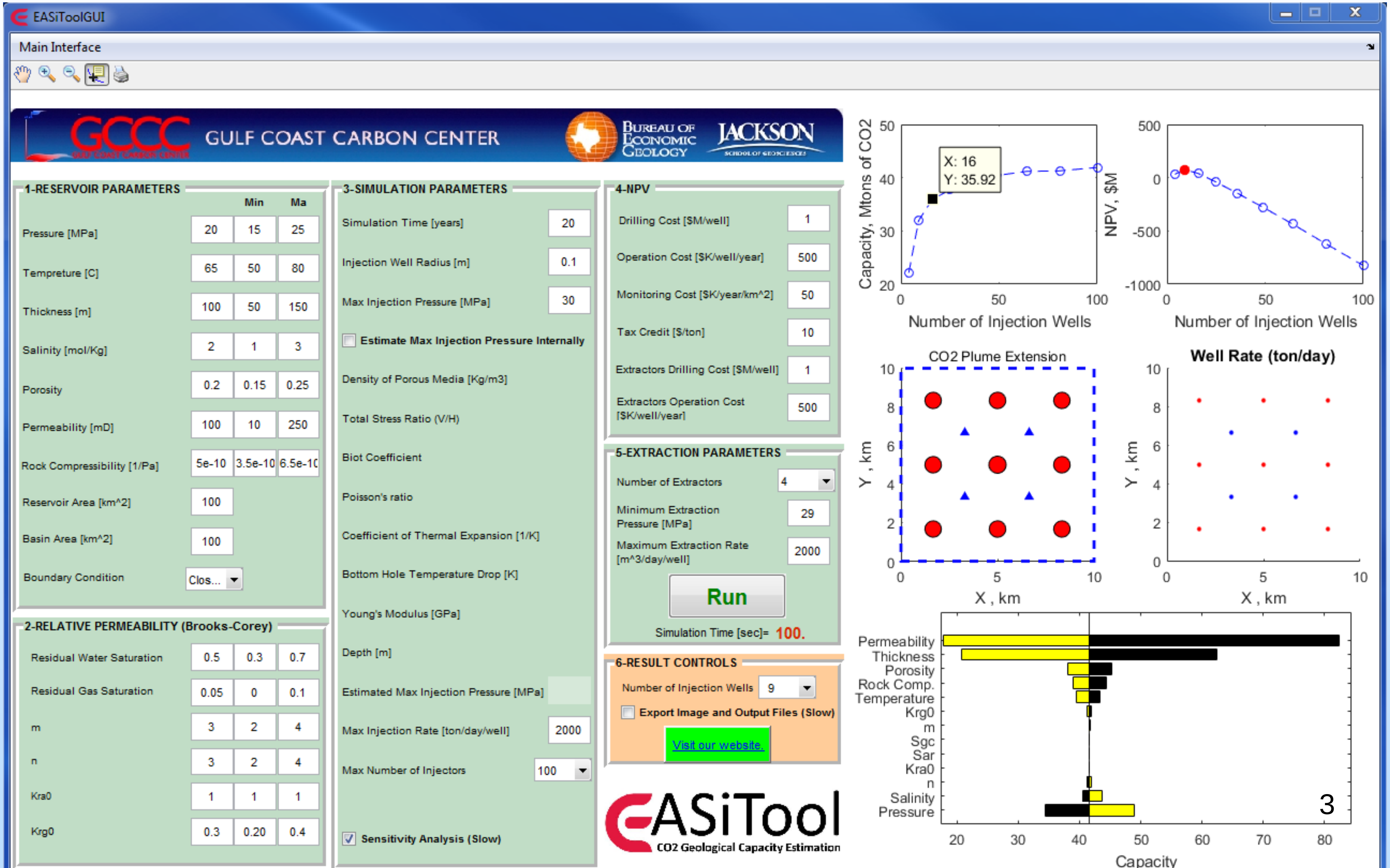
Benefit to the Program/Goals and Objectives

- <u>Project benefit</u>
  - Support industry's ability to predict CO_2 storage capacity in geologic saline formations to within ±30 percent.
- <u>Major goal</u>
  - Develop an **Enhanced Analytical Simulation Tool (EASiTool)** for simplified reservoir models to predict storage capacity of brine formations.
- <u>Objectives</u>
  - Provide fast, reliable and science-based estimate of storage capacity.
  - Integrate analytical/semi-analytical geomechanical models
  - Integrate brine extraction scenarios.
  - Provide sensitivity analysis.

Technical Status



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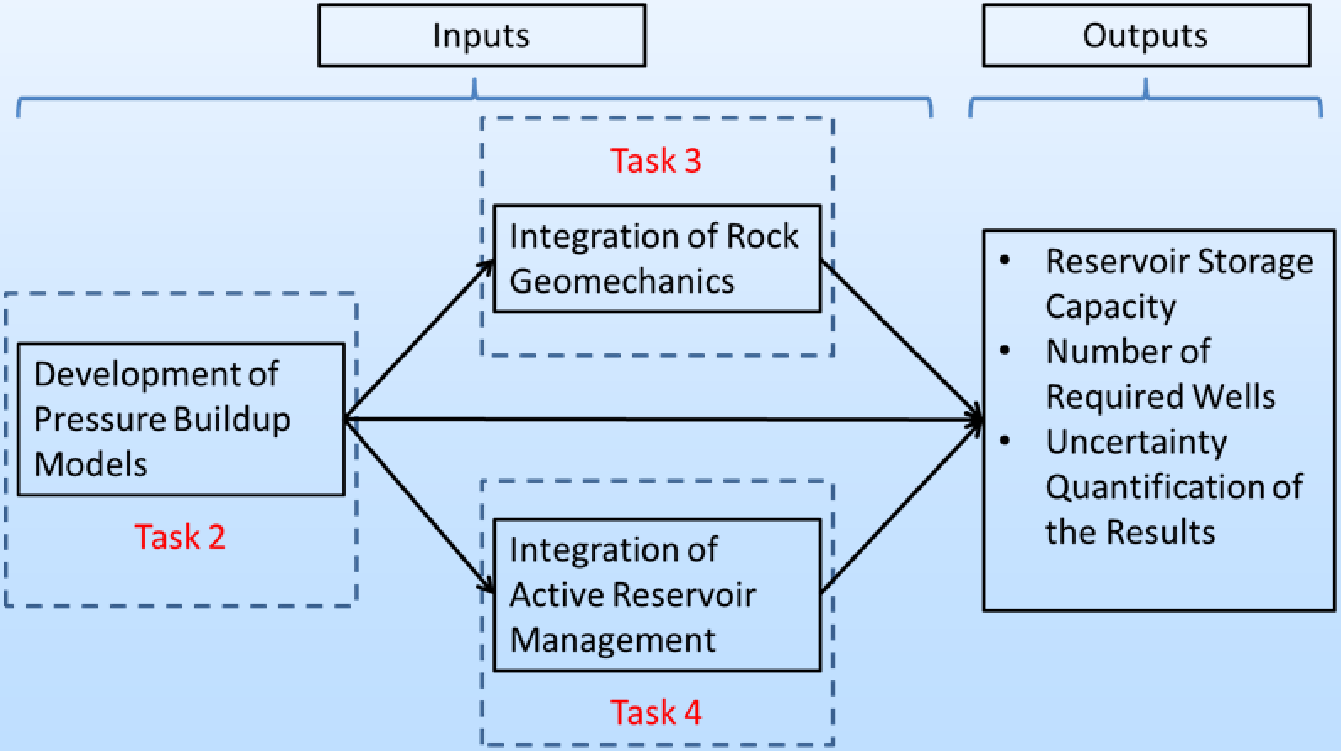
Technical Status

Tool/Approach Name	DOE/NETL	CSLF	USGS	EASiTool	Numerical Simulators
Reservoir scale	Yes	Yes	Yes	Yes	Yes
Accuracy	Low	Low	Low	Medium/High	High
Boundary conditions	No	No	No	Yes	Yes
Rock geomechanics	No	No	No	Yes	Yes
Brine management	No	No	No	Yes	Yes
Required expertise	Low	Low	Low	Low	High
Cost of use	Low	Low	Low	Low	High
Speed	High	High	High	High	Low
Dynamic	No	No	No	Yes	Yes
Sensitivity Analysis	No	No	Simple	Yes	Yes

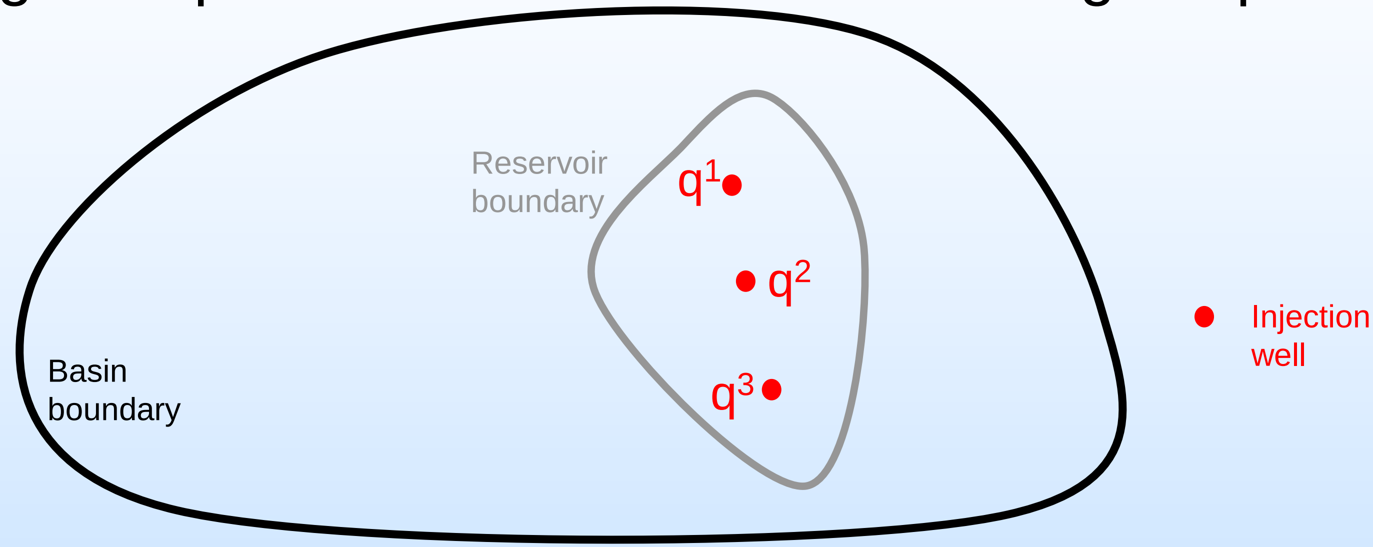
Technical Status

- Tasks 2-4 completed
- NCE
- User feedback, Verification & Application



Accomplishments to Date

- Finding the optimized rate to maximize storage capacity



$$\begin{bmatrix} \frac{1}{2}(\ln(t_D)+0.80908)+S_a & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D1-2}^2}{4\eta_{D3}t_D}\right) & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D1-3}^2}{4\eta_{D3}t_D}\right) \\ -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D2-1}^2}{4\eta_{D3}t_D}\right) & \frac{1}{2}(\ln(t_D)+0.80908)+S_a & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D2-3}^2}{4\eta_{D3}t_D}\right) \\ -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D3-1}^2}{4\eta_{D3}t_D}\right) & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\lambda_w}}E_i\left(-\frac{r_{D3-2}^2}{4\eta_{D3}t_D}\right) & \frac{1}{2}(\ln(t_D)+0.80908)+S_a \end{bmatrix} \begin{Bmatrix} q^1 \\ q^2 \\ q^3 \end{Bmatrix} = \begin{Bmatrix} \frac{2\pi hk\overline{k_{rg}}}{\mu_g}\Delta P_{\max} \\ \frac{2\pi hk\overline{k_{rg}}}{\mu_g}\Delta P_{\max} \\ \frac{2\pi hk\overline{k_{rg}}}{\mu_g}\Delta P_{\max} \end{Bmatrix}$$

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Accomplishments to Date

- Normal fault system

$$P_{\max} = \frac{1}{\left[2\alpha - \beta_v - \beta_h - (\beta_v - \beta_h)\cos 2\theta + (\beta_v - \beta_h)\sin 2\theta / \mu\right]} \cdot$$

$$\left[\{(1+K) + (1-K)\cos 2\theta - (1-K)\sin 2\theta / \mu\}\sigma_{v0} - \{(\beta_v + \beta_h) + (\beta_v - \beta_h)\cos 2\theta - (\beta_v - \beta_h)\sin 2\theta / \mu\}P_{pi} - \frac{2\alpha_T E\Delta T}{1-2\nu}\right]$$

- Reverse fault system

$$P_{\max} = \frac{1}{\left[2\alpha - \beta_h - \beta_v - (\beta_h - \beta_v)\cos 2\theta + (\beta_h - \beta_v)\sin 2\theta / \mu\right]} \cdot$$

$$\left[\{(K+1) + (K-1)\cos 2\theta - (K-1)\sin 2\theta / \mu\}\sigma_{v0} - \{(\beta_h + \beta_v) + (\beta_h - \beta_v)\cos 2\theta - (\beta_h - \beta_v)\sin 2\theta / \mu\}P_{pi} - \frac{2\alpha_T E\Delta T}{1-2\nu}\right]$$

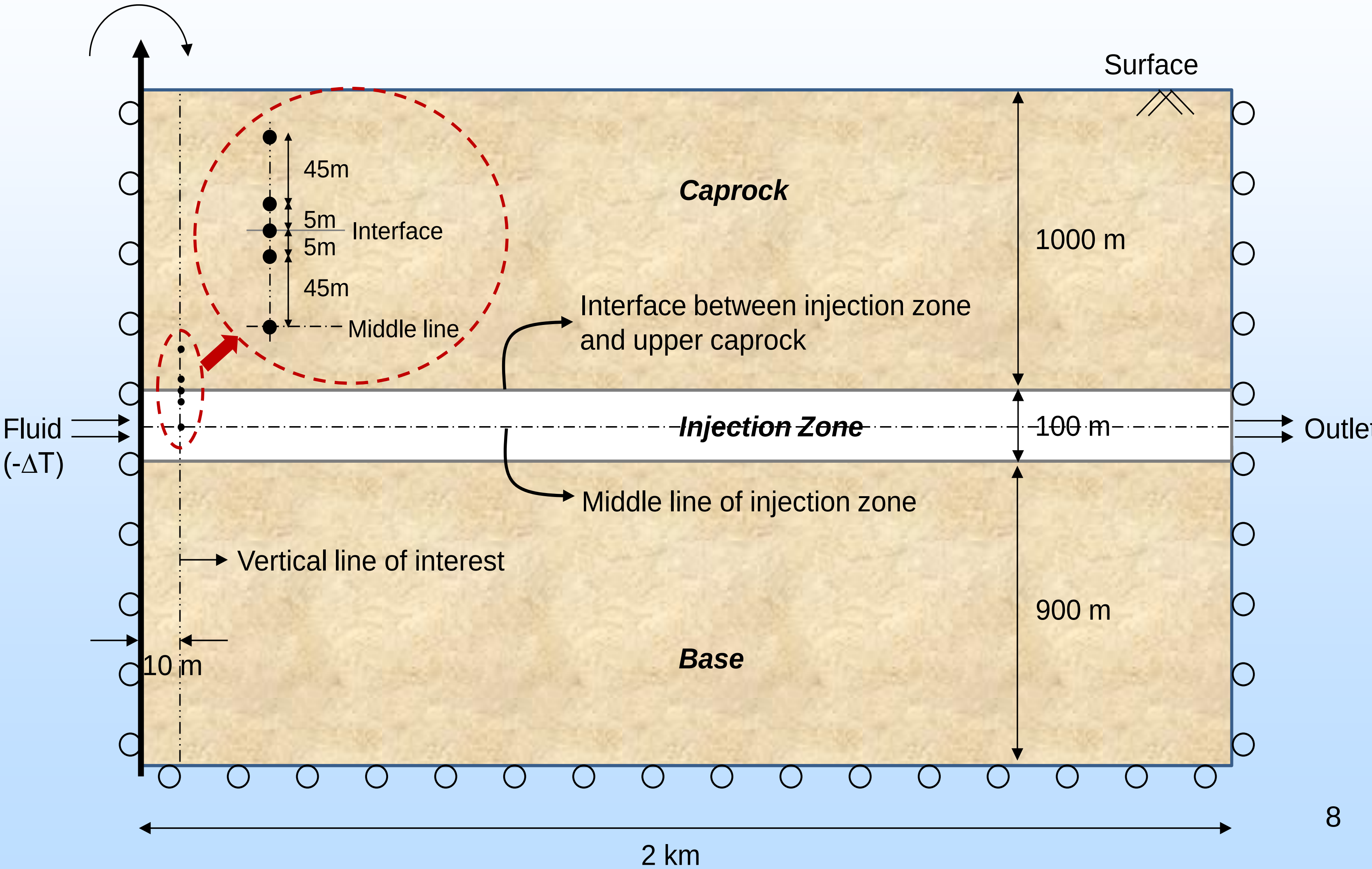
- Strike-slip fault system

$$P_{\max} = \frac{1}{\alpha - \beta_h}\left[\left(\frac{1+K_H}{2} + \frac{1-K_H}{2}\cos 2\theta - \frac{1-K_H}{2}\sin 2\theta / \mu\right)\sigma_{H0} - \beta_h \cdot P_{pi} - \frac{\alpha_T E\Delta T}{1-2\nu}\right]$$

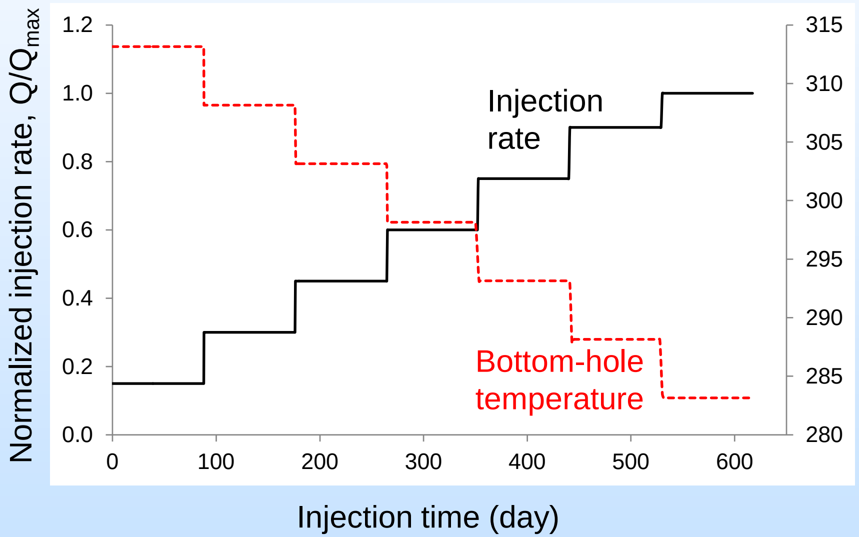
$$\Delta P_{max} = P_{max} - P_{pi}$$

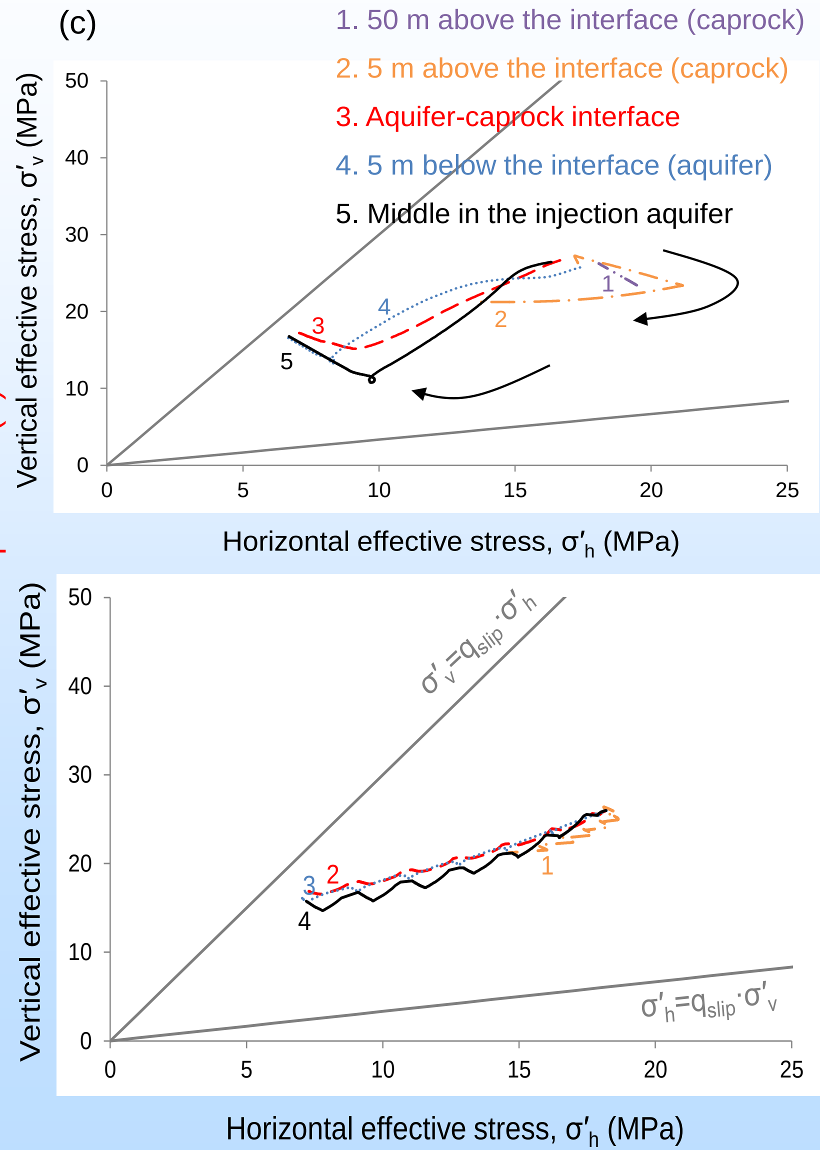
- Kim, S, and Hosseini, S. A., 2014, Geological CO_2 storage: incorporation of pore-pressure/stress coupling and thermal effects to determine maximum sustainable pressure limit: Energy Procedia, v. 63, p. 3339-3346,
- Kim, S, and Hosseini, S. A., 2016, Study on the Ratio of Pore-Pressure/Stress Changes During Fluid Injection and Its Implications for CO2 Geologic Storage, Journal of Petroleum Science and Engineering, in press.

Accomplishments to Date

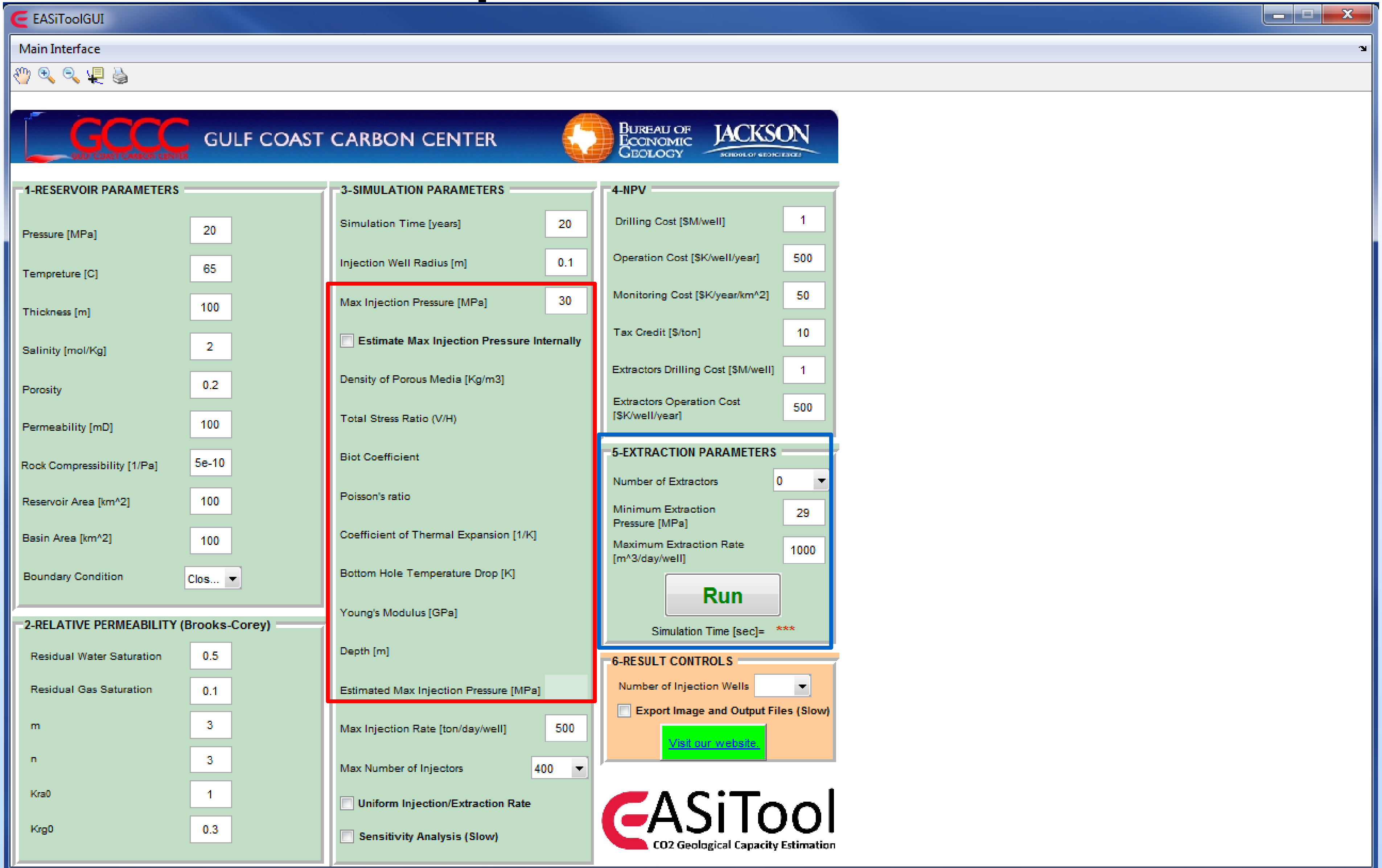


Accomplishments to Date



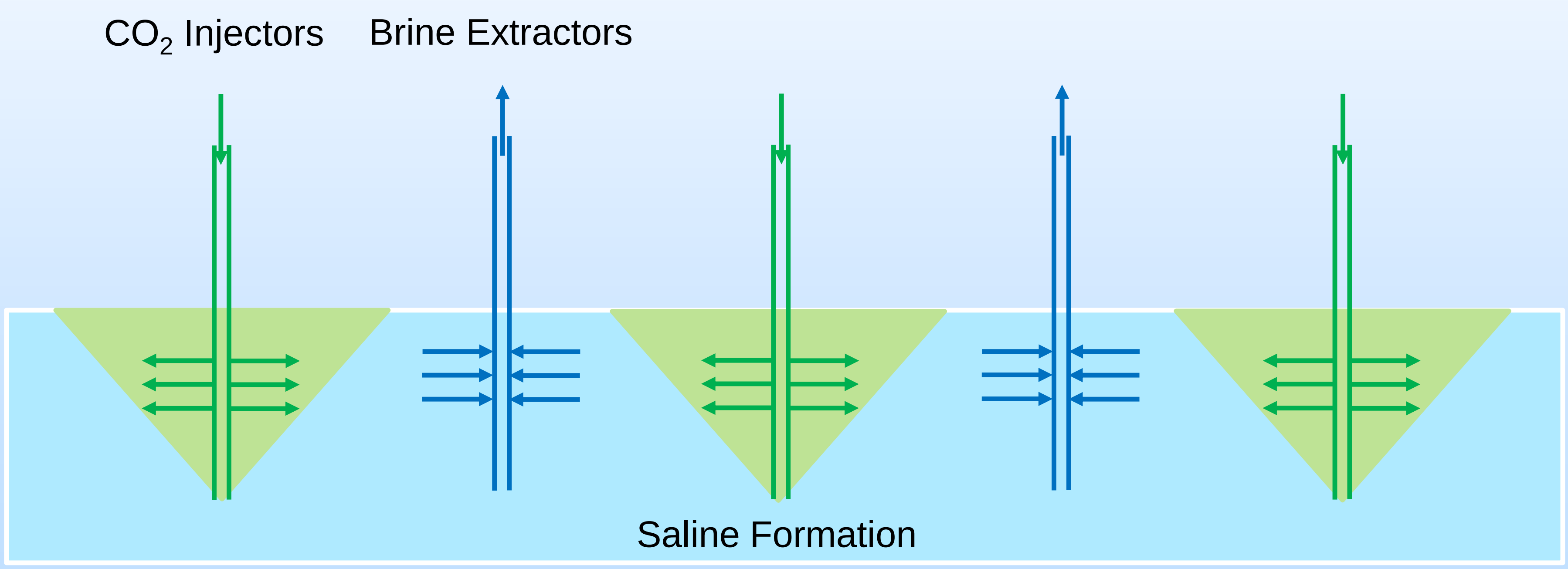


Accomplishments to Date



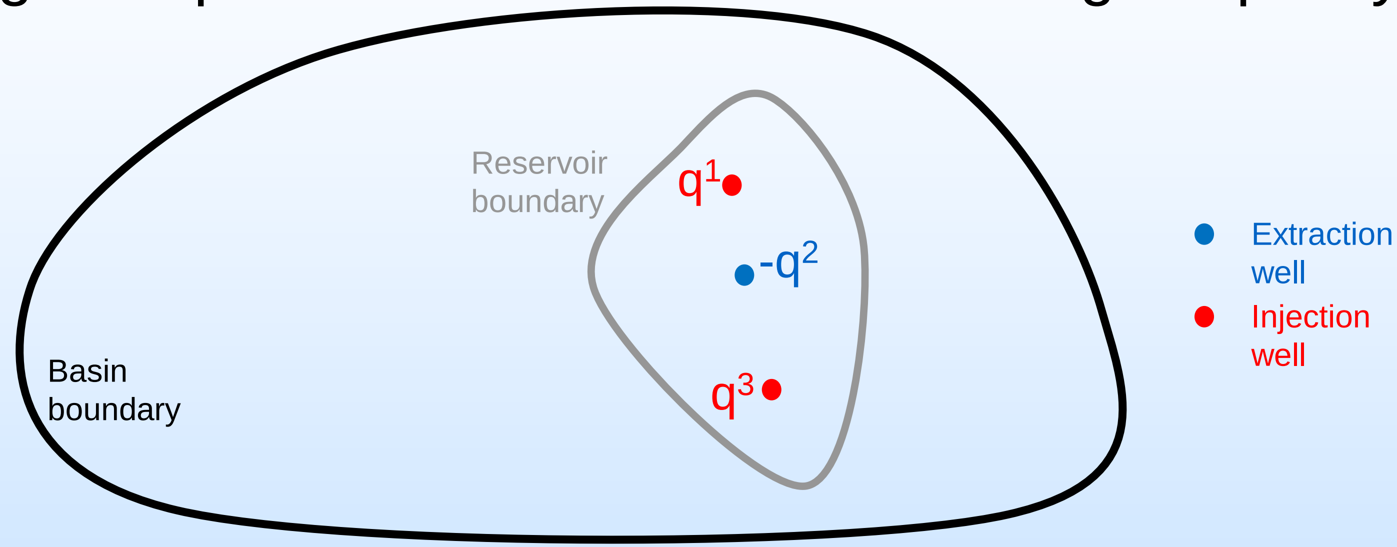
Brine Extraction

- Brine extraction improves injectivity (capacity) and reduce the risk of exceeding the fracture pressure.



Accomplishments to Date

- Finding the optimized rate to maximize storage capacity



$$\begin{bmatrix} \frac{1}{2}\left(\ln(t_D)+0.80908\right)+S_a & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\overline{\lambda_w}}}E_i\left(-\frac{r_{D1-2}^2}{4\eta_{D3}t_D}\right) & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\overline{\lambda_w}}}E_i\left(-\frac{r_{D1-3}^2}{4\eta_{D3}t_D}\right) \\ -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\overline{\lambda_w}}}E_i\left(-\frac{r_{D2-1}^2}{4\eta_{D3}t_D}\right) & \frac{1}{2}\left(\ln(t_D)+0.80908\right)+S_a & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\overline{\lambda_w}}}E_i\left(-\frac{r_{D2-3}^2}{4\eta_{D3}t_D}\right) \\ -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\overline{\lambda_w}}}E_i\left(-\frac{r_{D3-1}^2}{4\eta_{D3}t_D}\right) & -\frac{1}{2}\frac{\overline{\lambda_g}}{\overline{\overline{\lambda_w}}}E_i\left(-\frac{r_{D3-2}^2}{4\eta_{D3}t_D}\right) & \frac{1}{2}\left(\ln(t_D)+0.80908\right)+S_a \end{bmatrix} \begin{Bmatrix} q^1 \\ -q^2 \\ q^3 \end{Bmatrix} = \begin{Bmatrix} \frac{2\pi hk\overline{k_{rg}}}{\mu_g}\Delta P_{\max} \\ \frac{2\pi hk\overline{k_{rg}}}{\mu_g}\Delta P_{\min} \\ \frac{2\pi hk\overline{k_{rg}}}{\mu_g}\Delta P_{\max} \end{Bmatrix}$$

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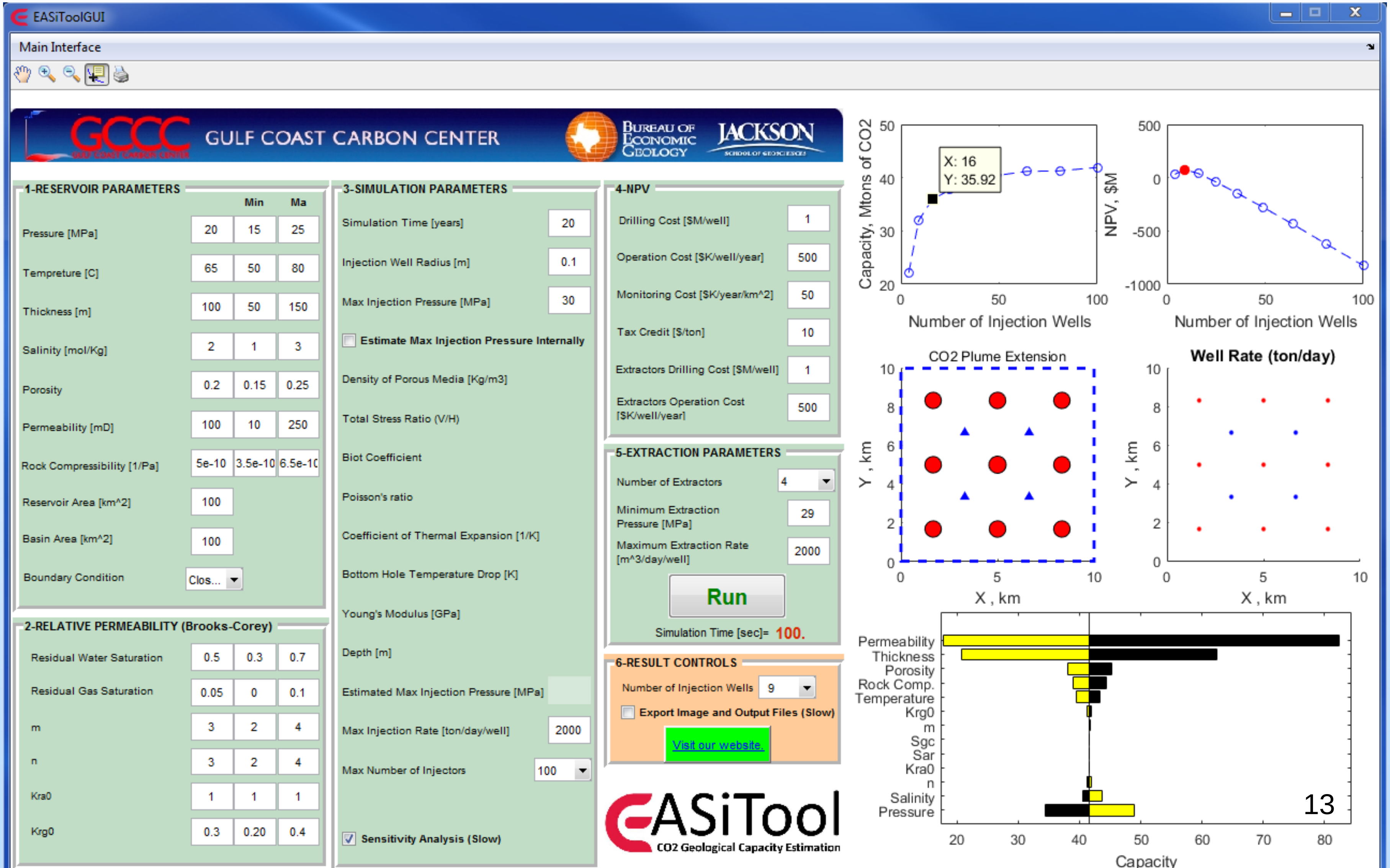
Closed Boundary, 4 Extractors



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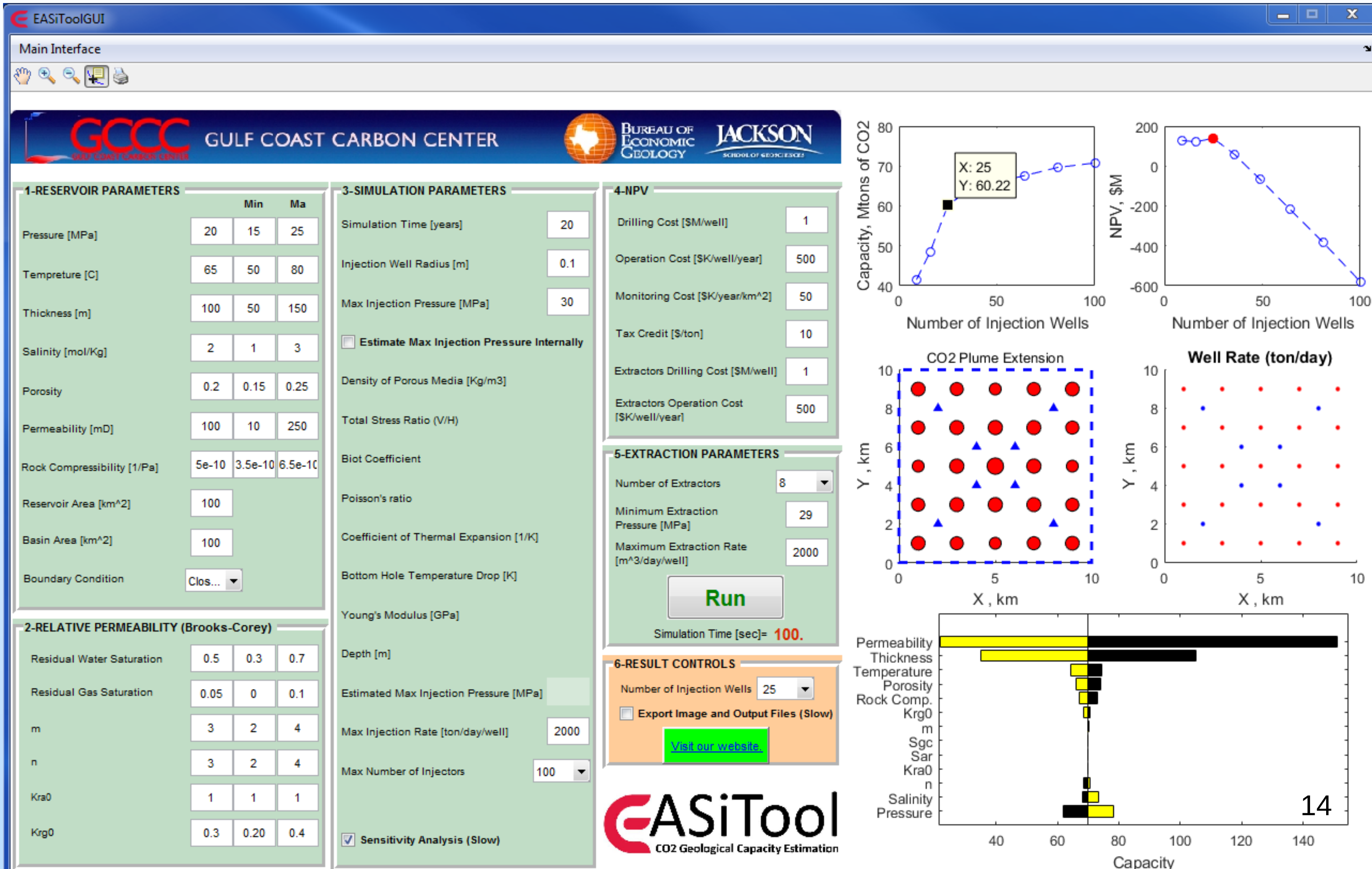
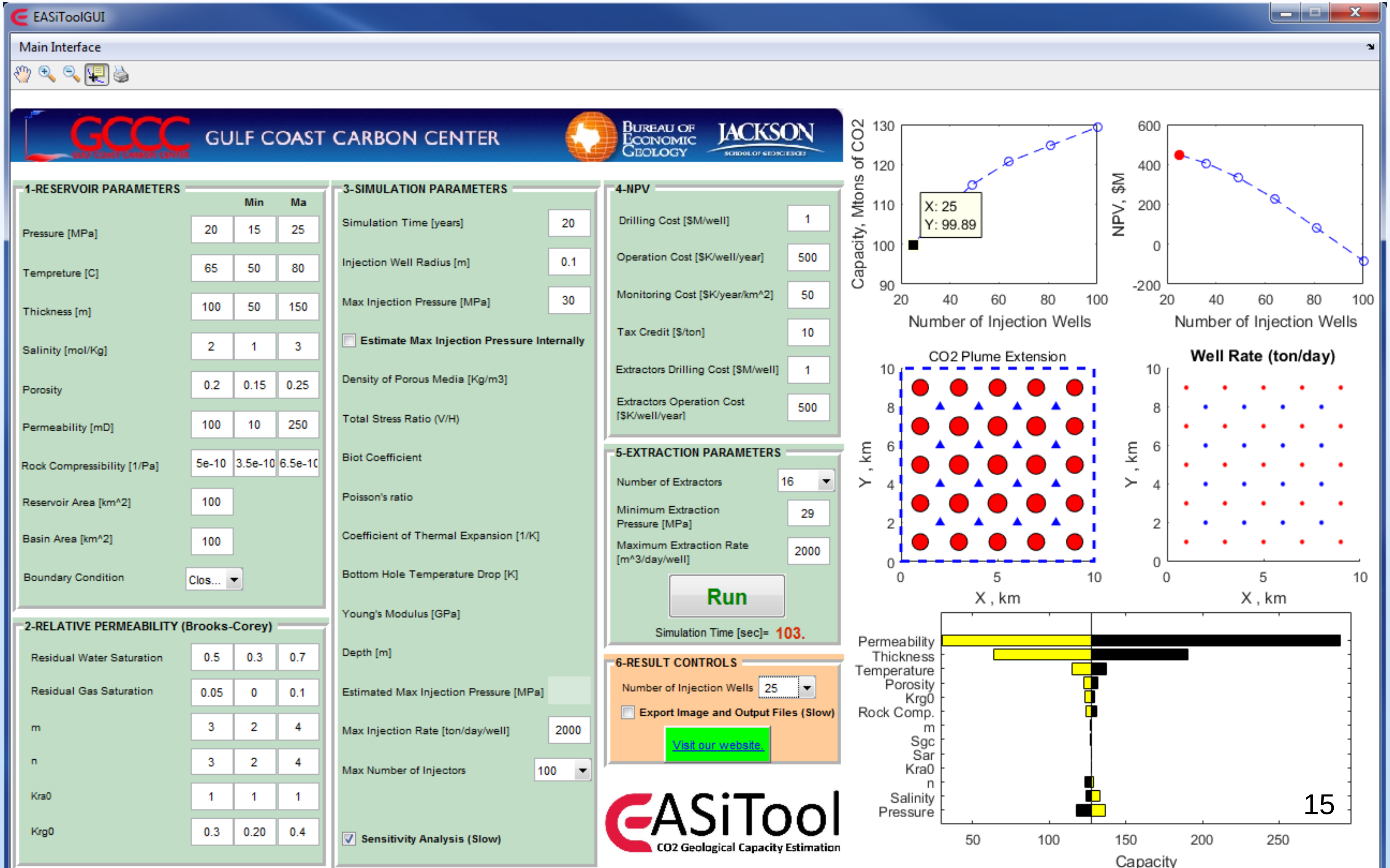
Closed Boundary, 8 Extractors



Closed Boundary, 16 Extractors



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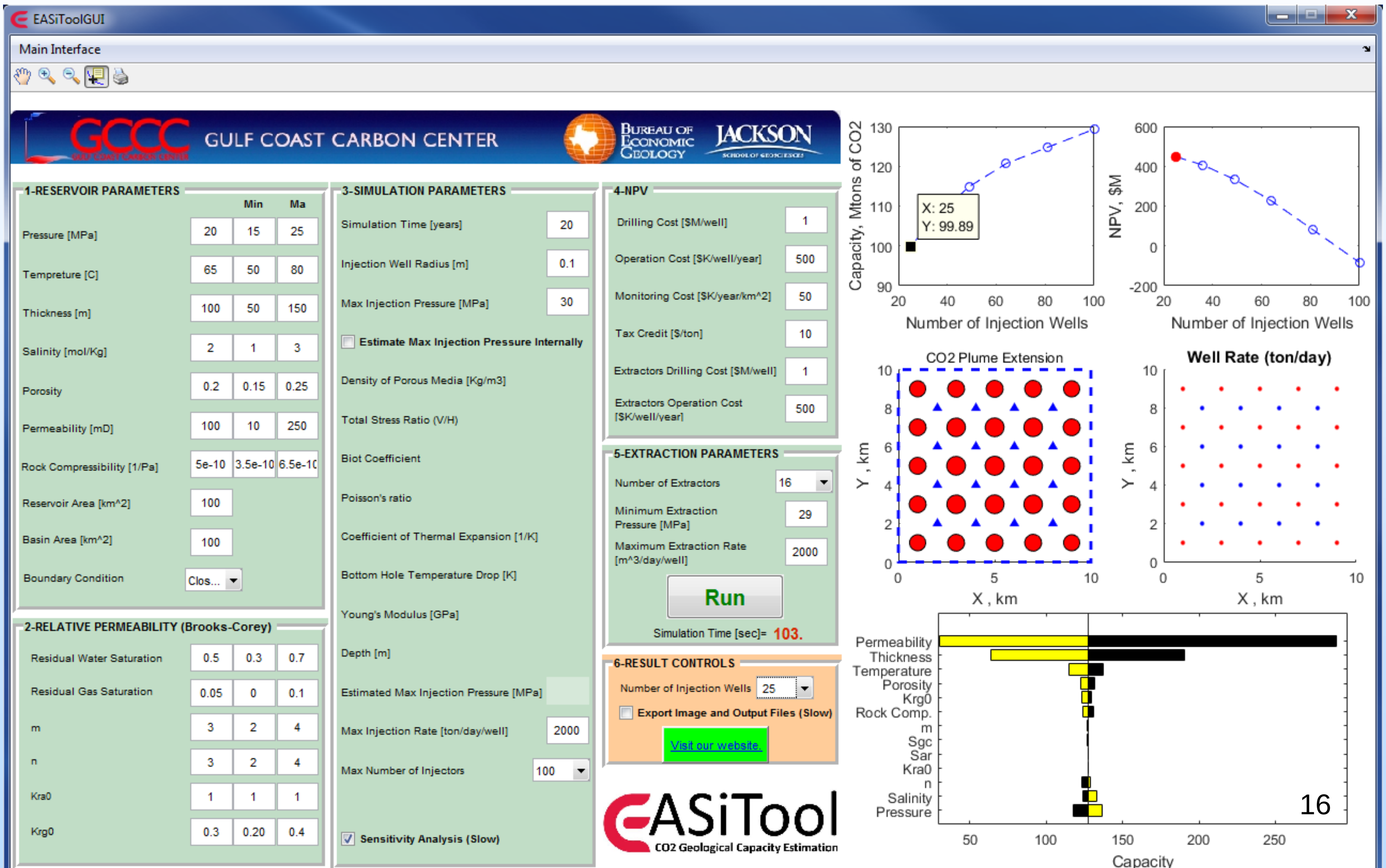
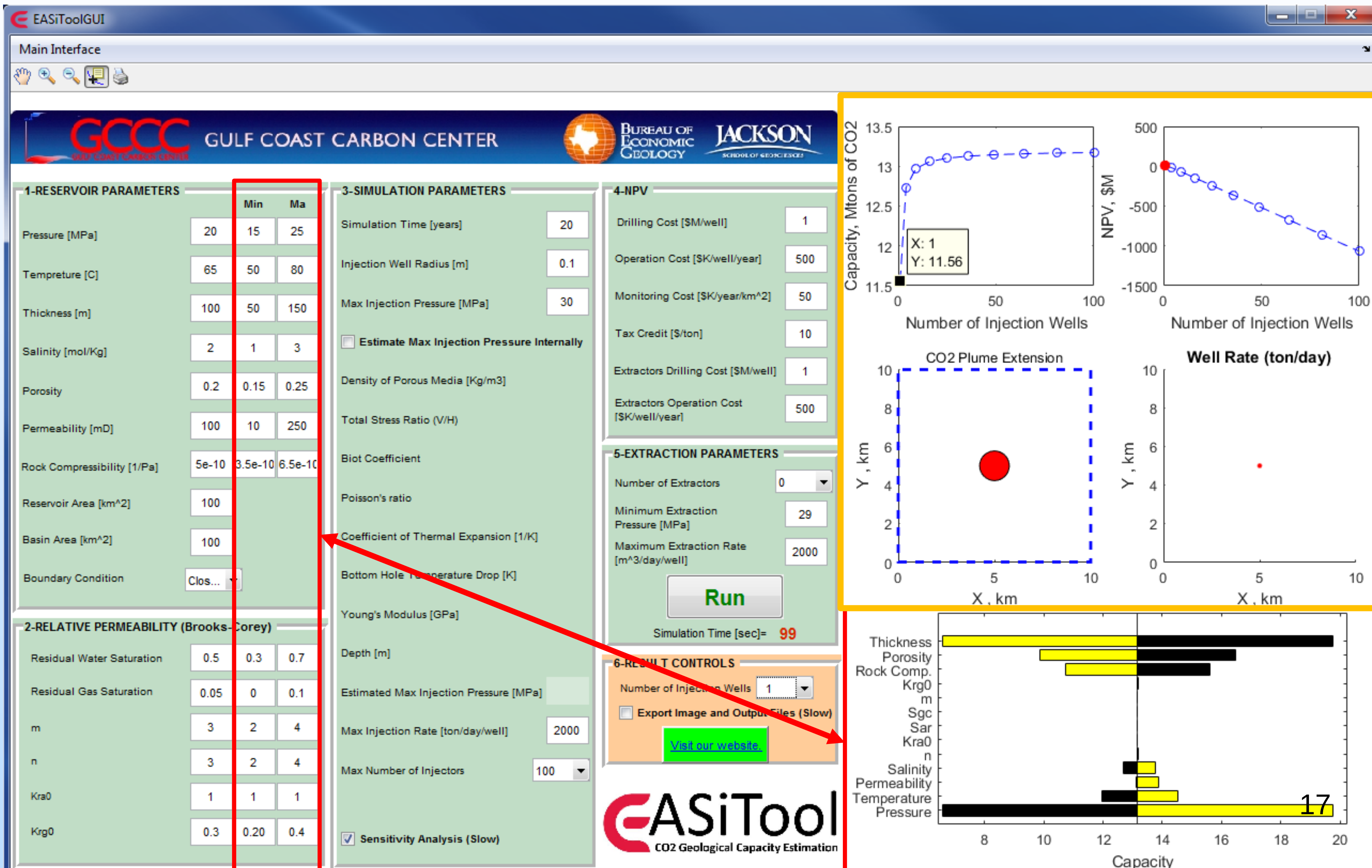
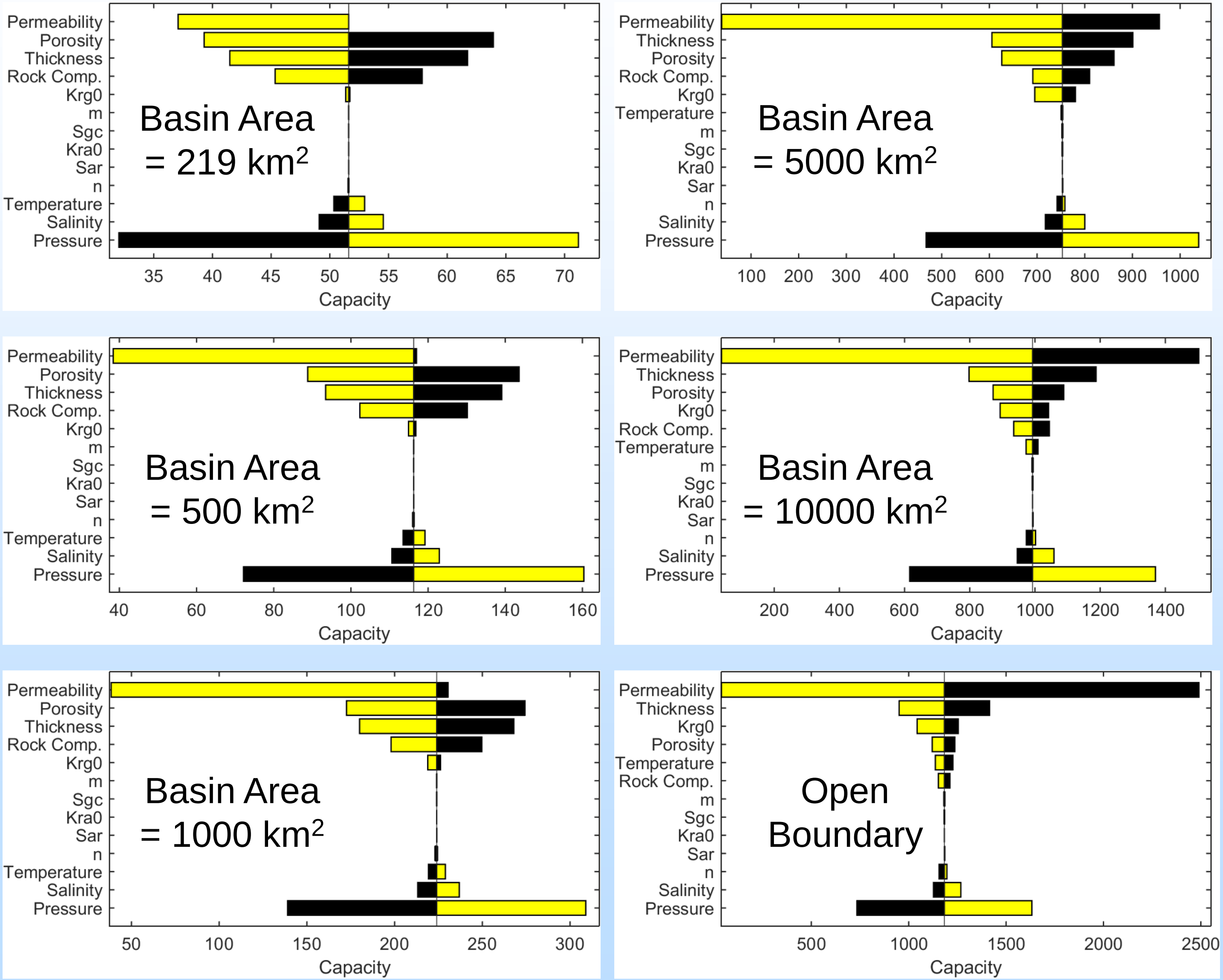
Closed Boundary, 16 Extractors



Sensitivity Analysis



Reservoir Area = 219 km^2



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Synergy Opportunities

– EASiTool is an analytical simulation tool for capacity estimation in saline aquifers.

– Input data required for EASiTool is typically available for most of the projects.

– EASiTool results can be compared with the results obtain in other projects via other methods (static, simulation, etc).

Future Plans

- User defined locations for injection and extraction wells
  - Adding multiple reservoirs within the same basin
  - Pressure maps
- Improving the user interface
- Improving sensitivity analysis
- Application of to USGS database (36 Basins)
- Funding to maintain and further develop EASiTool

Summary

- Third version of EASiTool has been released.
- Calculations for maximum injection pressure.
  - Integrates thermal and pore pressure stresses.
- Brine extraction option.
- Constant rate injection option.
- Sensitivity analysis.
- EASiTool is available for download:
  - http://www.beg.utexas.edu/gccc/EASiTool/

END

» Questions/Comments

Appendix

– Organization Chart

– Gantt Chart

– Bibliography

– Extra Slides

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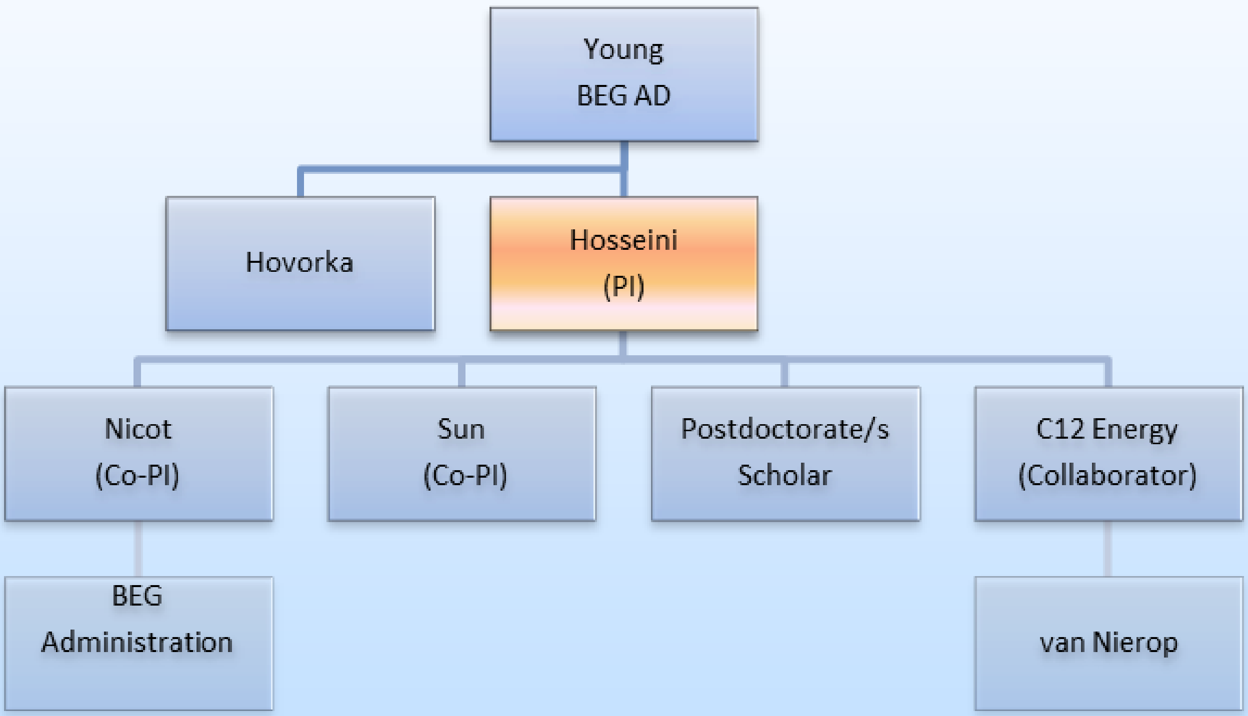
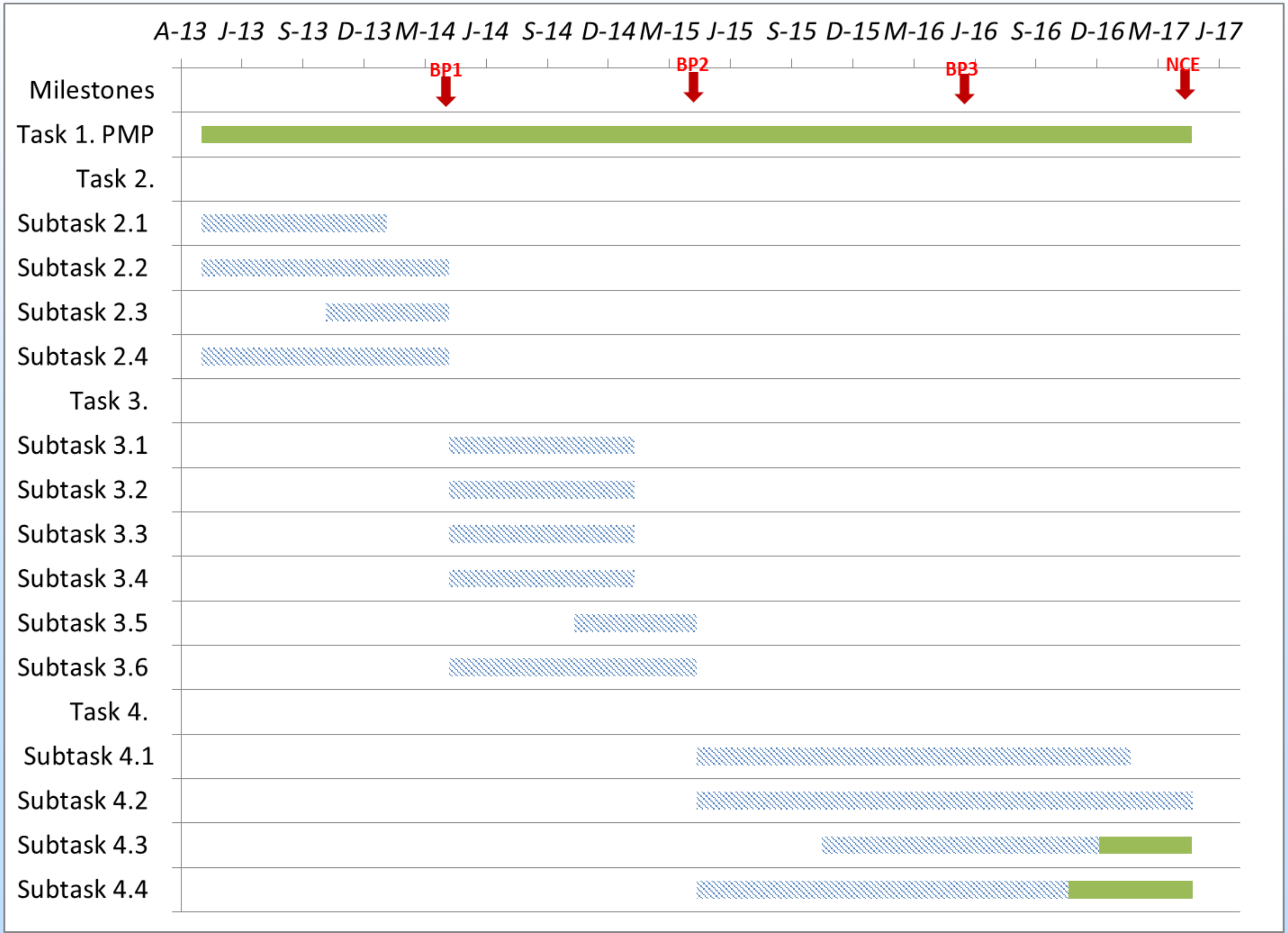
Organization Chart



Organization Chart

Project PI: Seyyed A. Hosseini			
Task 1 Project Management and Planning	**Task 2** Development of Analytical Solutions for Pressure Buildup	**Task 3** Rock Geomechanics Impact on Pressure Buildup and Capacity Estimation	**Task 4** Brine-Management Impact on CO_2 Injectivity and Storage Capacity
Task Leader/Backup Nicot/Hosseini	Task Leader/Backup Hosseini/Sun	Task Leader/Backup Hosseini/Sun	Task Leader/Backup Hosseini/Sun
Task 1 Team Nicot/Hosseini/ Young/Hovorka	Task 2 Team Subtask 2.1 Hosseini/Sun/ Postdoc/s Subtask 2.2 Hosseini/Sun/C12 Energy Subtask 2.3 Sun/Hosseini Subtask 2.4 Sun/Hosseini	Task 3 Team Subtask 3.1 Hosseini/Sun/ Postdoc/s Subtask 3.2 Hosseini/Sun/ Postdoc/s Subtask 3.3 Sun/Hosseini Subtask 3.4 Hosseini/Sun Subtask 3.5 Sun/Hosseini Subtask 3.6 Sun/Hosseini	Task 4 Team Subtask 4.1 Hosseini/Sun/ Postdoc/s Subtask 4.2 Sun/Hosseini/ Postdoc/s Subtask 4.3 Sun/Hosseini Subtask 4.4 Sun/Hosseini

Gantt Chart

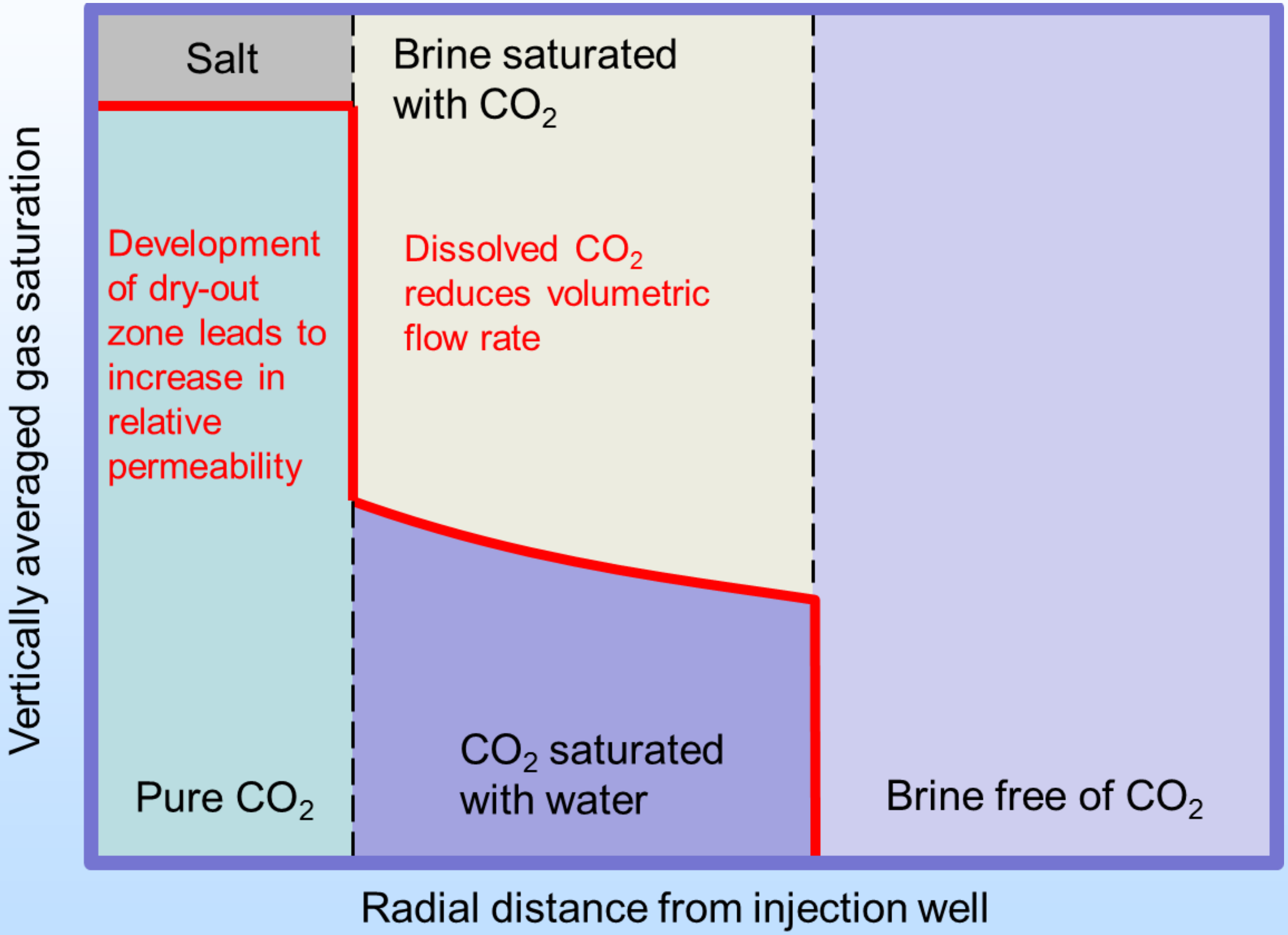

A-13 J-13 S-13 D-13 M-14 J-14 S-14 D-14 M-15 J-15 S-15 D-15 M-16 J-16 S-16 D-16 M-17 J-17
Milestones
BP1
BP2
BP3
NCE
Task 1. PMP
Task 2.
Subtask 2.1
Subtask 2.2
Subtask 2.3
Subtask 2.4
Task 3.
Subtask 3.1
Subtask 3.2
Subtask 3.3
Subtask 3.4
Subtask 3.5
Subtask 3.6
Task 4.
Subtask 4.1
Subtask 4.2
Subtask 4.3
Subtask 4.4

Bibliography

– Journals
  - Kim, S., Hosseini, S.A, 2013, Above-zone pressure monitoring and geomechanical analyses for a field-scale CO_2 injection project in Cranfield, MS, Greenhouse Gases: Science and Technology, 4 (1), 81-98, DOI: 10.1002/ghg.1388

– Conferences
  - Kim, Seunghee, Hosseini, S. A., and Hovorka, S. D., 2013, Numerical Simulation: Field Scale Fluid Injection to a Porous Layer in relevance to CO_2 Geological Storage: Proceedings of the 2013 COMSOL Conference, Boston, Massachusetts.
  - Kim, Seunghee, Hosseini, S. A., 2014, Optimization of Injection Rates for Geological CO_2 Storage in Brine Formations, 13th Annual Conference on Carbon Capture Utilization & Storage.
  - Kim, Seunghee, Hosseini, S. A., 2014, Effect of Pore Pressure/Stress Coupling on Geological CO_2 Storage, 13th Annual Conference on Carbon Capture Utilization & Storage.

Analytical model



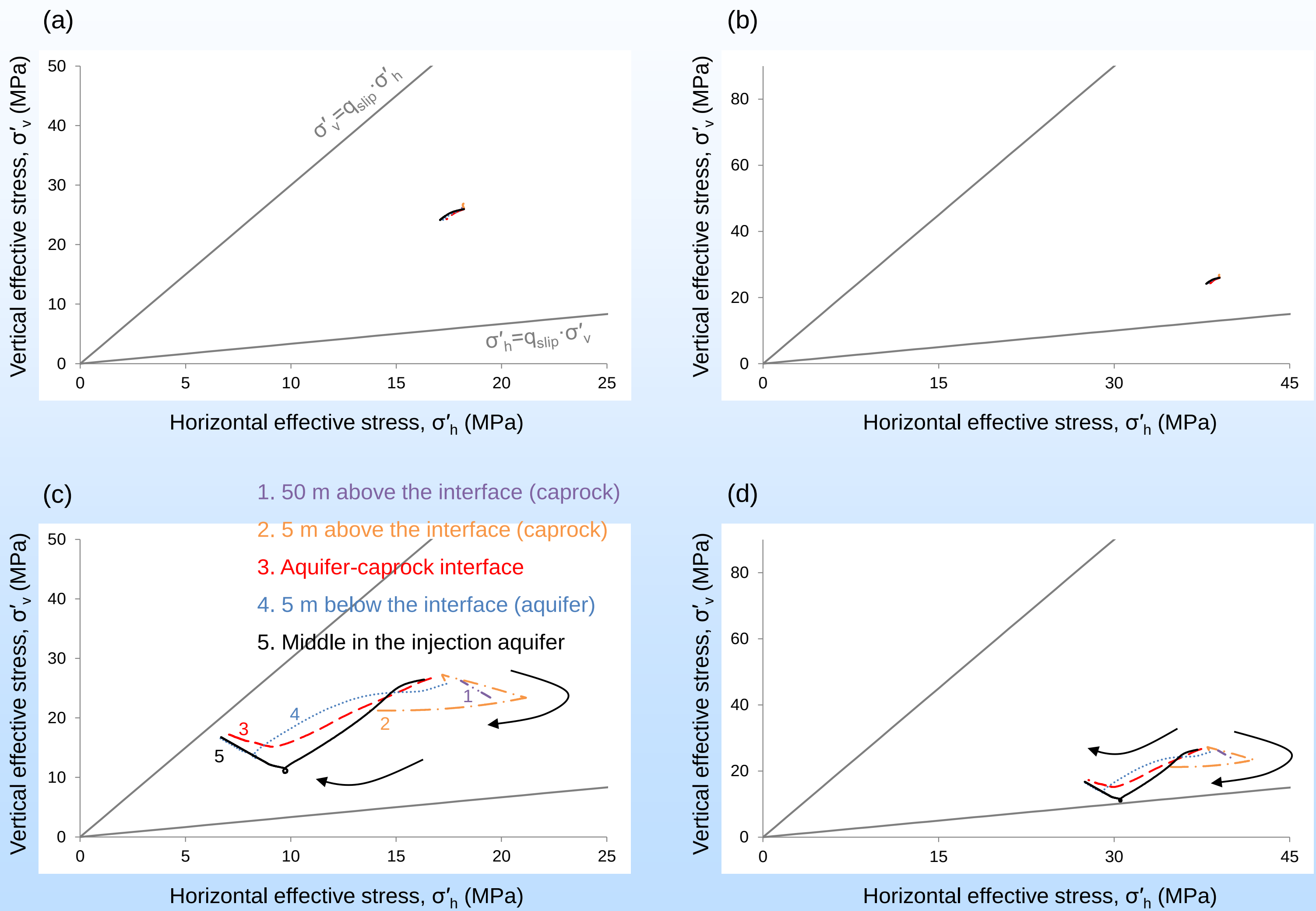
Accomplishments to Date

- Pore pressure stress coupling
  - Change in total stress ($\Delta\sigma$)is coupled with change in pore pressure(ΔP).
  - We define $\beta_h=\Delta\sigma_h/\Delta P$ and $\beta_v=\Delta\sigma_v/\Delta P$ & typically $\beta_h>\beta_v$
- Thermal stress
  - Injected CO_2 is generally colder than formation brine.
  - shrinkage of the rock formation (specially near the injection well) by $\sigma^{\Delta T} = 2\alpha_T E \Delta T / (1-2\vartheta)$
- Mohr-Coulomb shear failure criterion

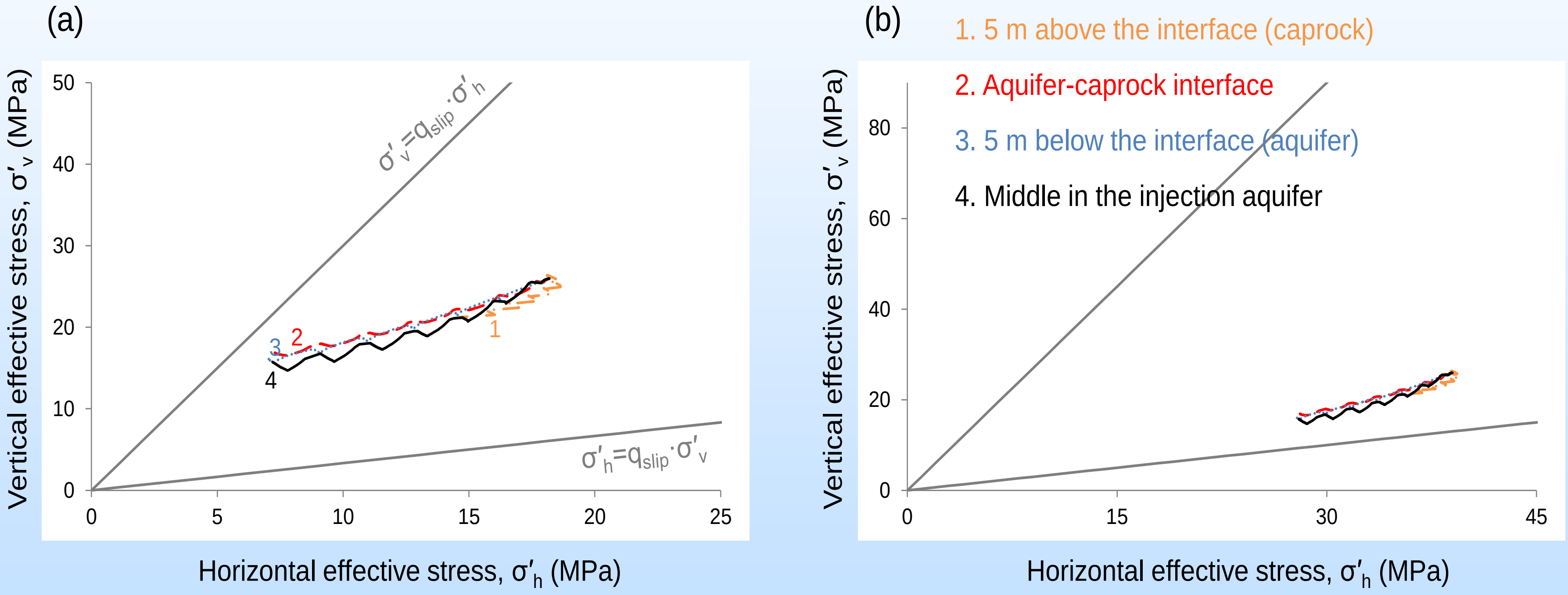
$$\tau=c+(\sigma_n-\alpha\cdot P_{max})\mu$$

Kim, S, and Hosseini, S. A., 2014, Geological CO_2 storage: incorporation of pore-pressure/stress coupling and thermal effects to determine maximum sustainable pressure limit: Energy Procedia, v. 63, p. 3339-3346, http://doi.org/10.1016/j.egypro.2014.11.362.

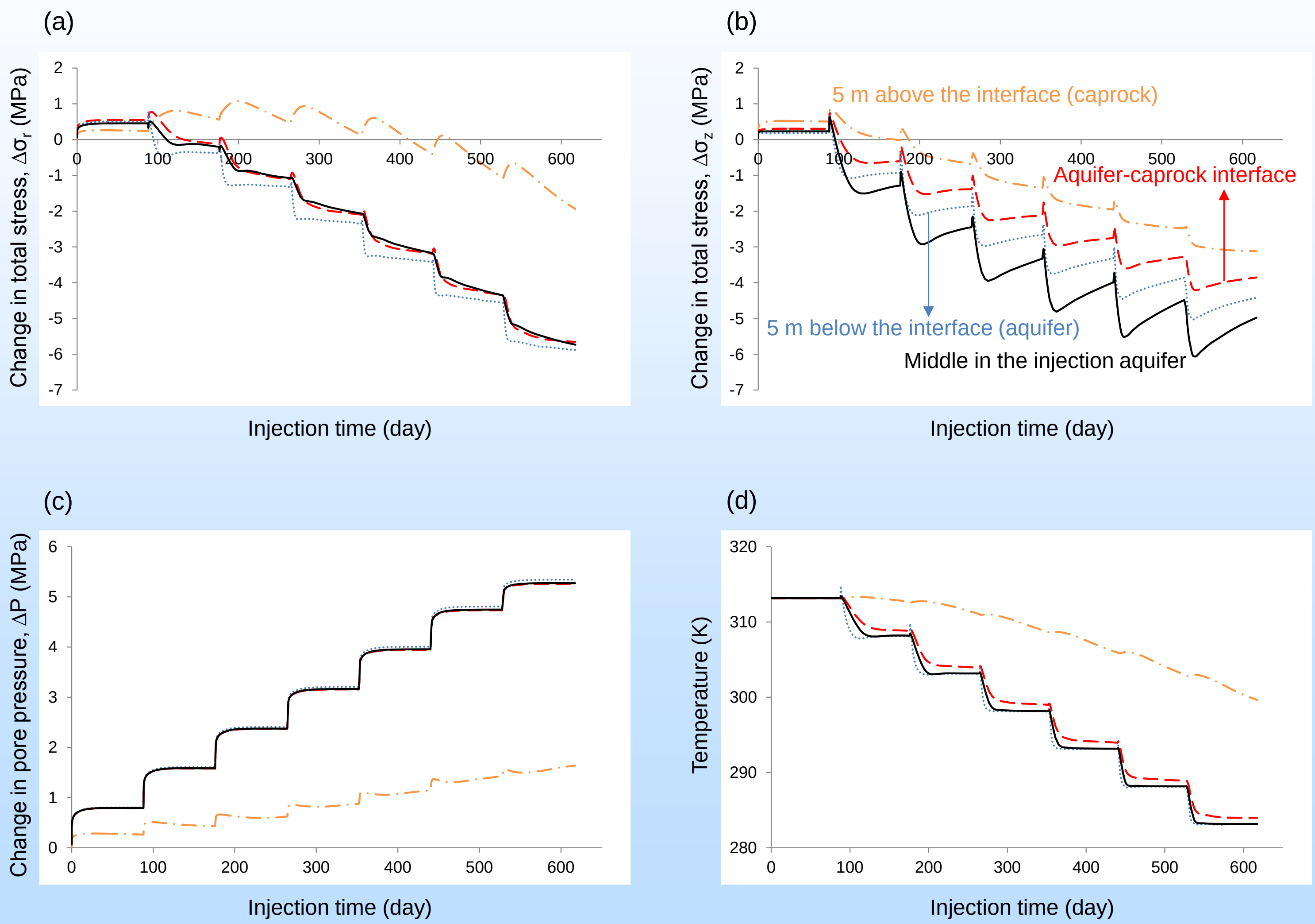
Accomplishments to Date



Accomplishments to Date-10



Accomplishments to Date-9



Verification of EASiTool Models