Task 4: Active Reservoir Management
(See FEW-0191)

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Presentation outline

• Active reservoir management (ARM) of geologic CO₂ storage (GCS) in open reservoirs
  – managing reservoir pressure of adjoining GCS and saltwater disposal (SWD) operations, analyzed with model constrained with data from the Energy & Environmental Research Center (EERC) Brine Extraction Storage Test (TEST) site

• ARM analyses for a hypothetical GCS operation next to a SWD operation for a 10.5-year period when SWD data is available

• ARM analyses for the hypothetical GCS and SWD operations extended by 19.5 years for 30 years of operation

• Accomplishments to date

• Lessons learned

• Synergy opportunities

• Project summary
Technical Status: Active Reservoir Management (ARM) for GCS in open reservoirs

- EERC has provided LLNL geologic information and 58 years of well data for saltwater disposal (SWD) operations near the BEST site, located in the Inyan Kara Fm. in the Williston Basin
  - deep saline formation (DSF), is a large open reservoir underlying nearly all of North Dakota and large portions of neighboring states
  - > 700 SWD wells injecting > 400 million barrels during 2018, > 95% of SWD in ND, and is projected to reach 1 billion barrels per year by 2030
  - estimated CO$_2$ storage capacity of 20–80 billion tons (Glazewski et al, 2015) and recent unpublished analysis suggesting 2–5 times that

- Our focus has evolved into the use of ARM to leverage the advantages of open, large-capacity reservoirs through efficient integration of GCS with adjoining SWD operations

- We have extended our ARM analyses by an additional 19.5 years to consider a typical 30-year GCS project
Technical Status: Data-constrained model of the EERC BEST site

- The EERC BEST site has 5 SWD wells operating since 1961
- The EERC team has used a 6 x 6-mile reservoir model of this site
- Using a 100 x 100-km reservoir model, we confirmed that the Inyan Kara Fm. is an open reservoir
Technical Status: Data-constrained model of the EERC BEST site

- Our model agrees with field values of overpressure at the SWD wells
- Differences between simulated and field result from intermittent injection of co-produced brine, flowback water, and occasional fresh water
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- Our model agrees with field values of overpressure at the BEST-E1 well
- For our study we assume that the BEST-E1 (which is the brine extraction well in the EERC BEST project) is a passive observation well

Note: pressure data became available in November 2018
Technical Status: Data-constrained ARM analyses of the EERC BEST site

- We conducted a retrospective analysis of a 10.5-year GCS operation
  - injecting 2.0 MT/yr from October 1, 2008 to March 1, 2019
  - located close enough to the BEST site SWD wells for the pressure plumes to merge

![Diagram showing pressure plume and CO₂ plume areas.](attachment:diagram.png)
Our analyses indicate ARM can manage overpressure for 10.5 years of GCS and SWD operations separated by 2 km

- 7 brine production wells were used to remove 66,846 BPD, which was moved to 6 re-injection wells 20–30 km from the SWD wellfield.
- This corresponds to 6% of the total SWD in the Inyan Kara Fm. in 2018.
- Because operations only lasted 10.5 years, the pressure plumes of the SWD wells and brine re-injection wells did not coalesce.

![Graph showing overpressure over time for CIW 2 and BEST-E1 wells.]

Area ($\Delta P > 0.5$ MPa) = $346.4 \text{ km}^2$
Area ($\Delta P > 0.5$ MPa) = $9.4 \text{ km}^2$
Our analyses indicate ARM can manage overpressure for 30 years of GCS and SWD operations separated by 4 km.

- 30 years of injection necessitated moving the CO\textsubscript{2} injectors 2 km further away from the SWD field.
- To improve plume control, we added 2 brine producers, for a total of 9 brine producers.
- To add 19.5 years of injection data, SWD histories from Oct 1, 2012 through Oct 1, 2019 (when all 3 SWD wells were operating) were repeated 3 times.
- Coalescing pressure plumes necessitated extending brine removal 1 to 5 years beyond 30 years.
Our analyses indicate ARM can manage overpressure for 30 years of GCS and SWD operations separated by 4 km

- The pressure plumes from the CO$_2$ injectors and the SWD wellfield merge into one large plume
- After 30 years of SWD injection, the area where $\Delta P > 0.5$ MPa is 280 km$^2$
- After 30 years of SWD and CO$_2$ injection, the area where $\Delta P > 0.5$ MPa is 1134 km$^2$
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- The pressure plume is much larger than the CO₂ plume
- After 30 years of SWD and CO₂ injection, the area where ΔP > 0.5 MPa is 1134 km²
- After 30 years of CO₂ injection, the area where CO₂ saturation > 0.05 MPa is 19.4 km²
Our analyses indicate ARM can manage overpressure for 30 years of GCS and SWD operations separated by 4 km

- After 30 years of SWD and CO$_2$ injection
  - ARM reduces the area where $\Delta P > 0.5$ MPa from 1134 km$^2$ to 85.7 km$^2$ in the vicinity of the GCS operation
  - the pressure plume from the brine re-injection wells has reached the northeast corner of the SWD wellfield
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- 5 years after the end of SWD and CO$_2$ injection operations
  - the area where $\Delta P > 0.5$ MPa has increased to 1404 km$^2$ for SWD and CO$_2$ injection only
  - the pressure plume from the brine re-injection wellfield has merged with the plume surrounding the GCS and SWD wellfields, with the area where $\Delta P > 0.5$ MPa increasing to 1224 km$^2$
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  - the area where ΔP > 0.5 MPa has increased to 1404 km² for SWD and CO₂ injection only
  - the pressure plume from the brine re-injection wellfield has merged with the plume surrounding the GCS and SWD wellfields, with the area where ΔP > 0.5 MPa increasing to 1224 km²
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- While brine is actively produced, overpressure is controlled around the CO$_2$ and SWD injection wells
- After brine production stops, overpressure rebounds in the SWD wellfield as a result of the pressure plume from the brine re-injection wellfield
- Continuing brine production and re-injection for 5 more years prevents the rebound in overpressure from exceeding 0.5 MPa around the CO$_2$ and SWD injection wells
Our analyses indicate ARM can manage overpressure for 30 years of GCS and SWD operations separated by 4 km

- Continuing brine production and re-injection for 5 more years prevents the rebound in overpressure from exceeding 0.5 MPa in the vicinity of the SWD and CO₂ injection wells
- ARM limits the area where ΔP > 0.5 MPa to 8.2 km² in the vicinity of the GCS and SWD operations
Our analyses indicate ARM can manage overpressure for 30 years of GCS and SWD operations separated by 4 km

- Continuing brine production and re-injection for 5 more years prevents the rebound in overpressure from exceeding 0.5 MPa in the vicinity of the SWD and CO₂ injection wells
- ARM limits the area where ΔP > 0.5 MPa to 8.2 km² in the vicinity of the GCS and SWD wellfields
Accomplishments to Date

• Data-constrained reservoir model of the Snøhvit Phase I CO$_2$ Storage Project used to analyze ARM using pre-injection brine production.

• Data-constrained reservoir model of the Snøhvit Phase II CO$_2$ Storage Project used to analyze ARM with pre-injection gas production for associated storage.

• Data-constrained reservoir model analyses of the EERC BEST reservoir system in the Inyan Kara Fm. in the Williston Basin investigating how ARM can be used to minimize pressure interference between adjoining GCS and SWD operations.
Lessons Learned

- Active reservoir management (ARM) may be essential for GCS in limited-capacity, compartmentalized reservoirs.
- ARM can be useful in leveraging the inherent advantages of large-capacity, open reservoirs.
- ARM can enable co-locating GCS with other injection operations with minimal pressure interference between the operations.
- ARM may be useful in reducing monitoring costs.
- ARM may need to address all sources of reservoir overpressure, including those arising from other subsurface operations, such as saltwater disposal.
Synergy Opportunities

• Collaboration with BEST project team
• Conduct economic assessments and cost-benefit analyses that include the costs of ARM and monitoring
• Consider the impact of ARM on permitting and regulatory compliance
Project Summary

• Key findings
  – pressure plumes at GCS sites may be influenced by adjoining injection operations
  – to minimize the Area of Review (AoR), enough brine needs to be removed to account for all sources of overpressure, including adjoining injection operations
  – in large-capacity, open reservoirs, it may not be necessary to export brine out of that reservoir to minimize the AoR

• Next steps
  – seek collaboration opportunities for future, commercial-scale, GCS projects
Benefit to the Program

- Project goals that are being addressed include
  - active site characterization using pre-injection brine production
  - assurance of storage permanence

- Benefits to the program include
  - development of geologic CO$_2$-storage, reservoir-engineering strategies and related best practices that lead to increased assurance of storage permanence, while reducing monitoring costs
The project goals and objectives include the evaluation of strategies to increase CO$_2$ storage capacity in limited-capacity, compartmentalized reservoirs.

The project goals and objectives also include the evaluation of strategies to optimize ARM for waste-water and CO$_2$ injection using data from saltwater disposal operations in North Dakota, in collaboration with the Energy and Environmental Research Center (EERC), including those that:

- minimize the Area of Review
- prevent recirculation of injected fluids
- avoid pore-space trespass with neighboring subsurface operations
• The project team consists of Thomas Buscheck at Lawrence Livermore National Laboratory
Milestones

1. Publish journal article on pre-injection brine production using data-constrained model of Snøhvit Phase I project.
2. Publish two journal articles on pre-injection brine production.
4. Develop a data constrained reservoir model of the EERC BEST project in the Inyan Kara Fm.
5. Conduct Active Reservoir Management (ARM) analyses to investigate ARM options in the Inyan Kara Fm.
6. Present results of ARM study at 2019 CCUS and Oil & Gas Technologies Integrated Review Meeting.
8. Submit manuscript on Active Reservoir Management in the Inyan Kara Fm. in the Williston Basin, North Dakota.

