# Pressure Monitoring, Contingency Planning, and Mitigation of Leakage from $CO_2$ Storage Projects


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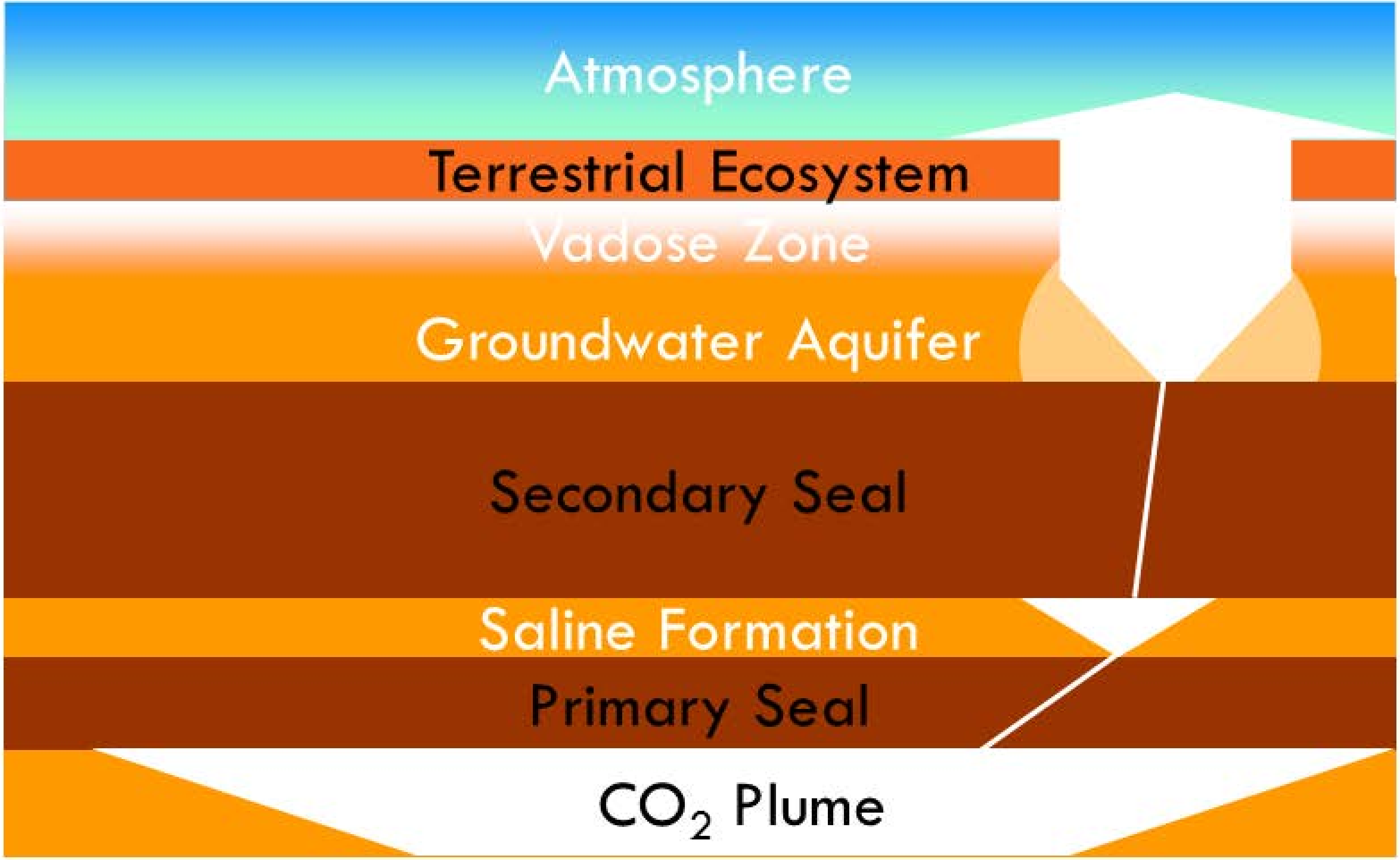
# Overview



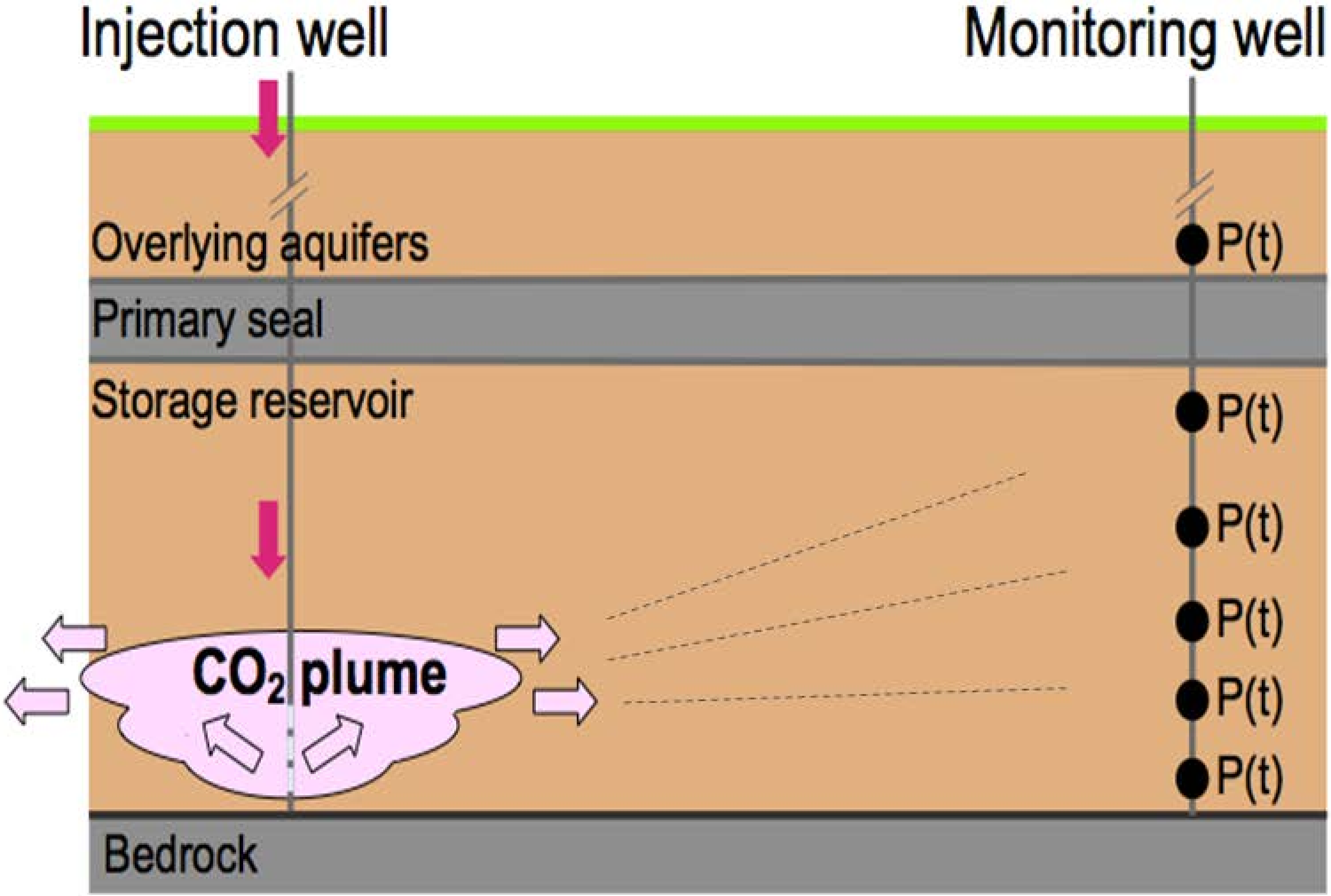
1. Pressure monitoring for plume migration early leak detection
2. Contingency planning for unexpected leakage
3. Mitigation methods for leakage management






## $CO_2$ Plume Migration and Leakage Monitoring

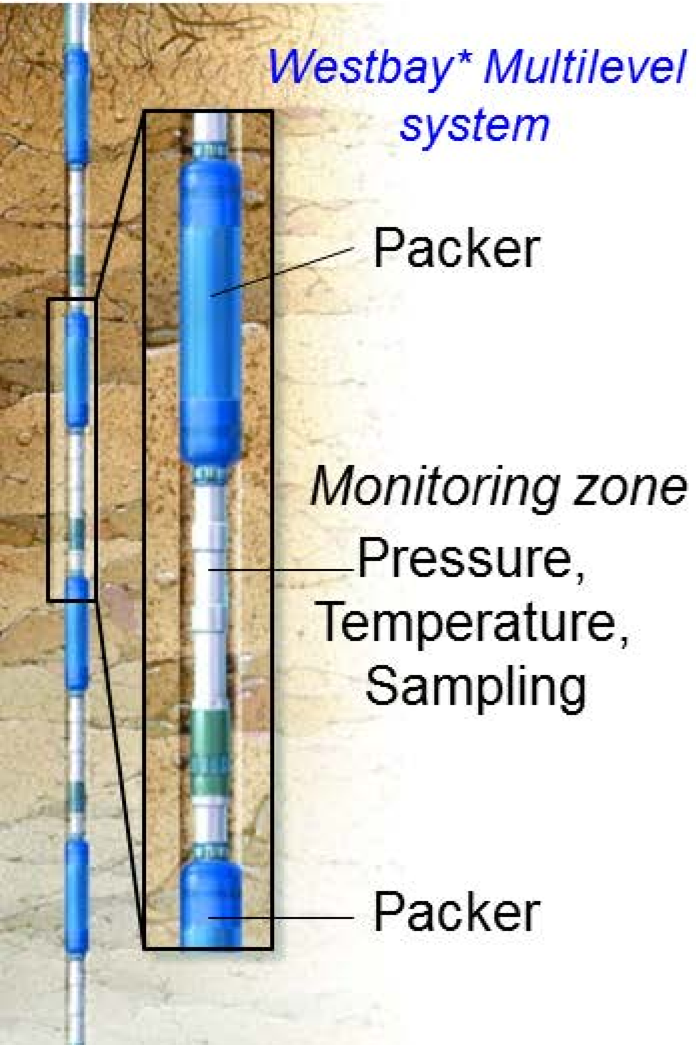
# Pressure Monitoring




Above Zone Monitoring

In Zone Monitoring

# In Zone Pressure Monitoring

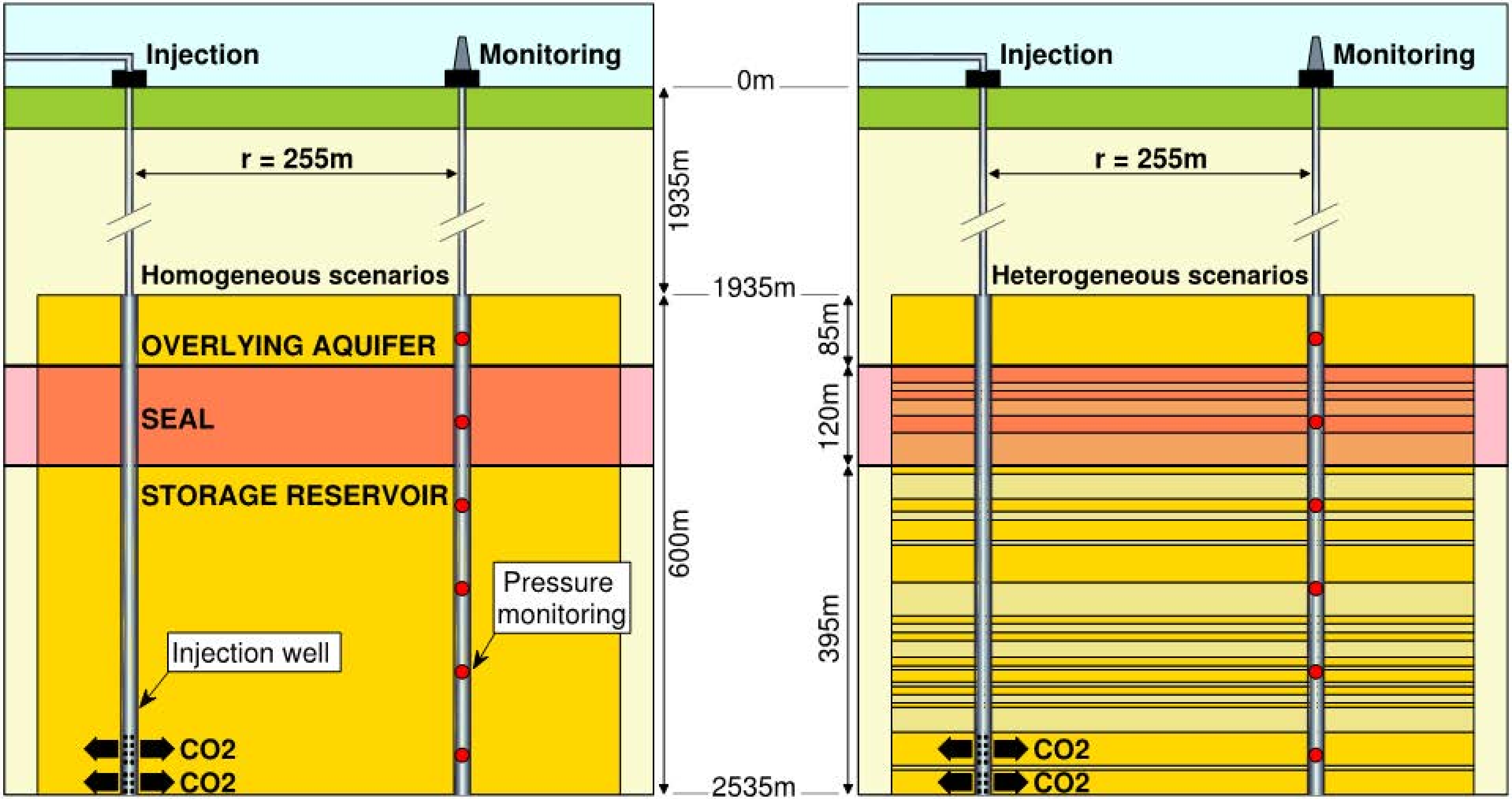



| Hydrogeology | CCS |
| --- | --- |
| Studies emphasize value of:<br>• Vertical pressure gradients<br>• High-resolution monitoring<br><br>E.g. Mercer and Spalding (1991); Parker et al. (2006); Fisher and Twining (2011) | 2008: Proposed implementation of the Westbay system at the **Illinois Basin – Decatur Project (IBDP)** (pilot project)<br>• **Motivation**: Available and promising<br>• 2011: Operational and first of its kind |

Multilevel Well Completions (product sheet)
http://www.slb.com/services/additional/water/monitoring/multilevel_well_system/well_completion.aspx

# Diagnostic Study: Can In Zone Measurements Track Plume Migration?





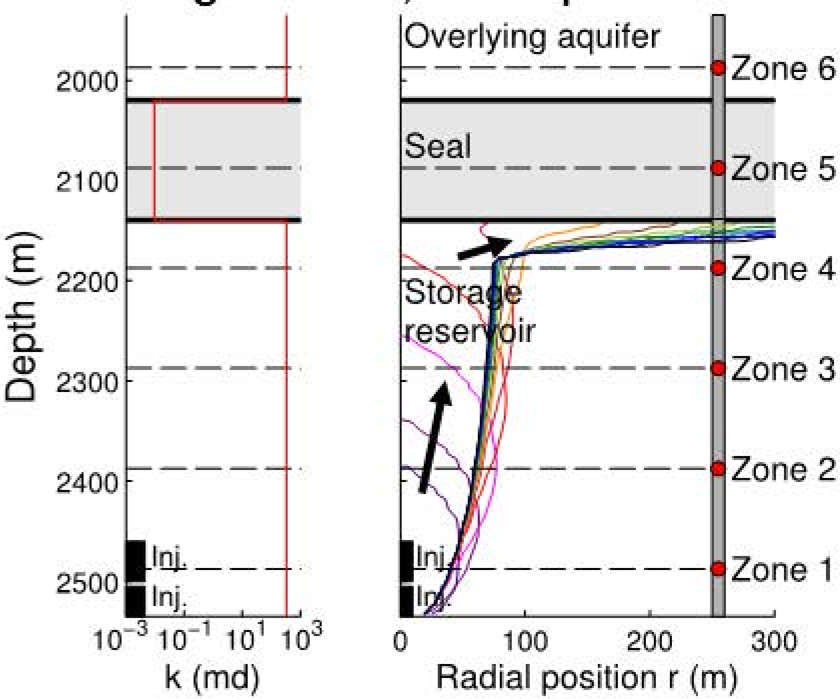

Strandli, C. W., & Benson, S. M. (2013). Identifying diagnostics for reservoir structure and CO2 plume migration from multilevel pressure measurements. *Water Resources Research*, *49*(6), 3462-3475.

# Different Reservoir Structures

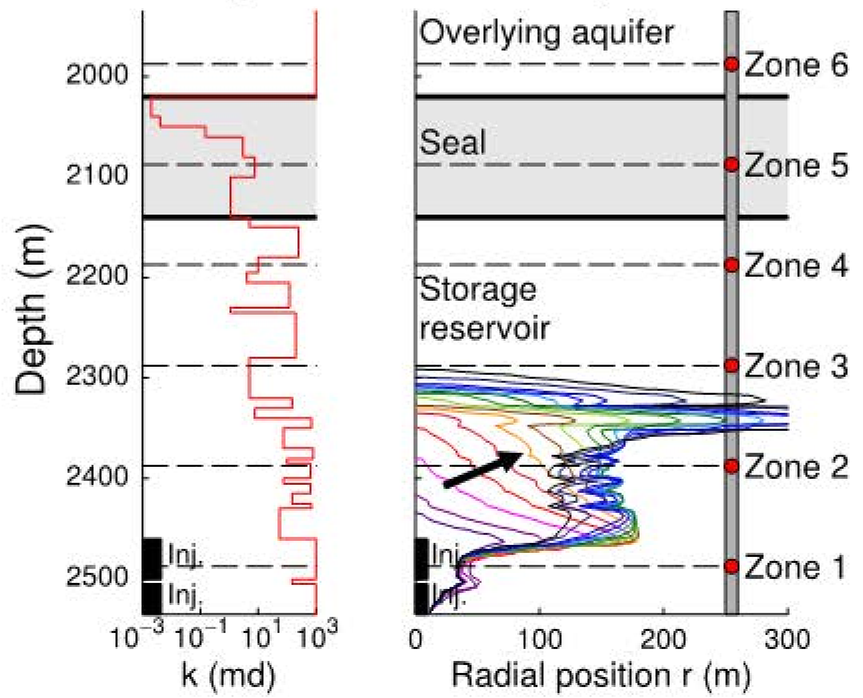


| | Homogeneous | Heterogeneous |
|---|---|---|
| Isotropic | x | x |
| Anisotropic | x | x |

## Homogeneous, isotropic scenario




## Heterogeneous, isotropic scenario

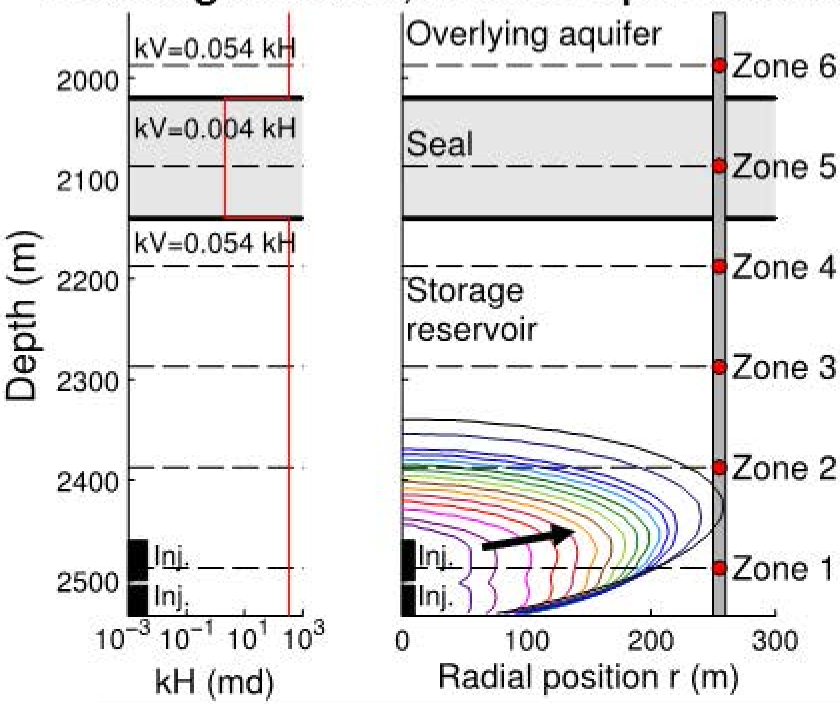


# Different Reservoir Structures

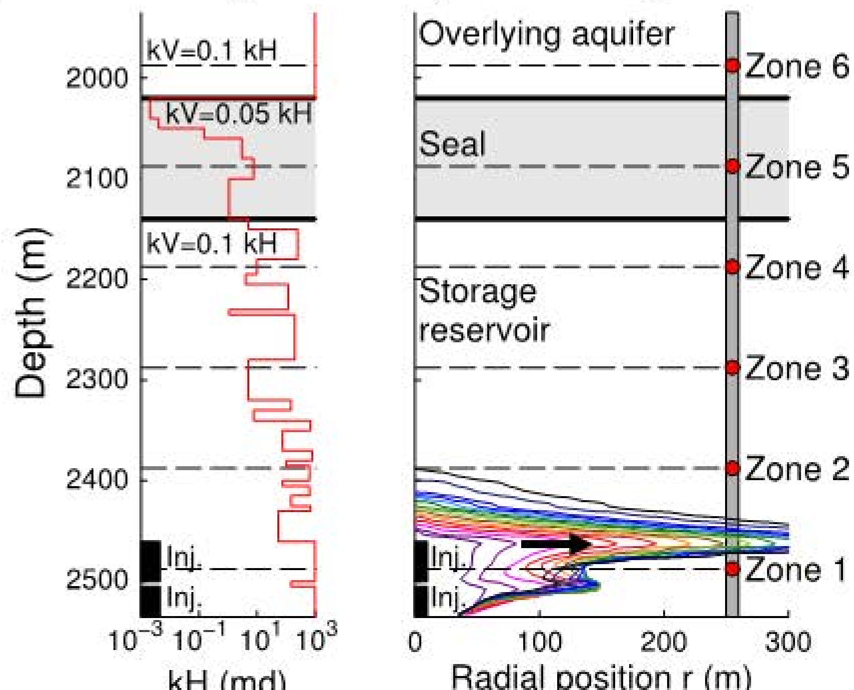


| | Homogeneous | Heterogeneous |
|---|---|---|
| Isotropic | X | X |
| Anisotropic | X | X |

## Homogeneous, anisotropic scenario

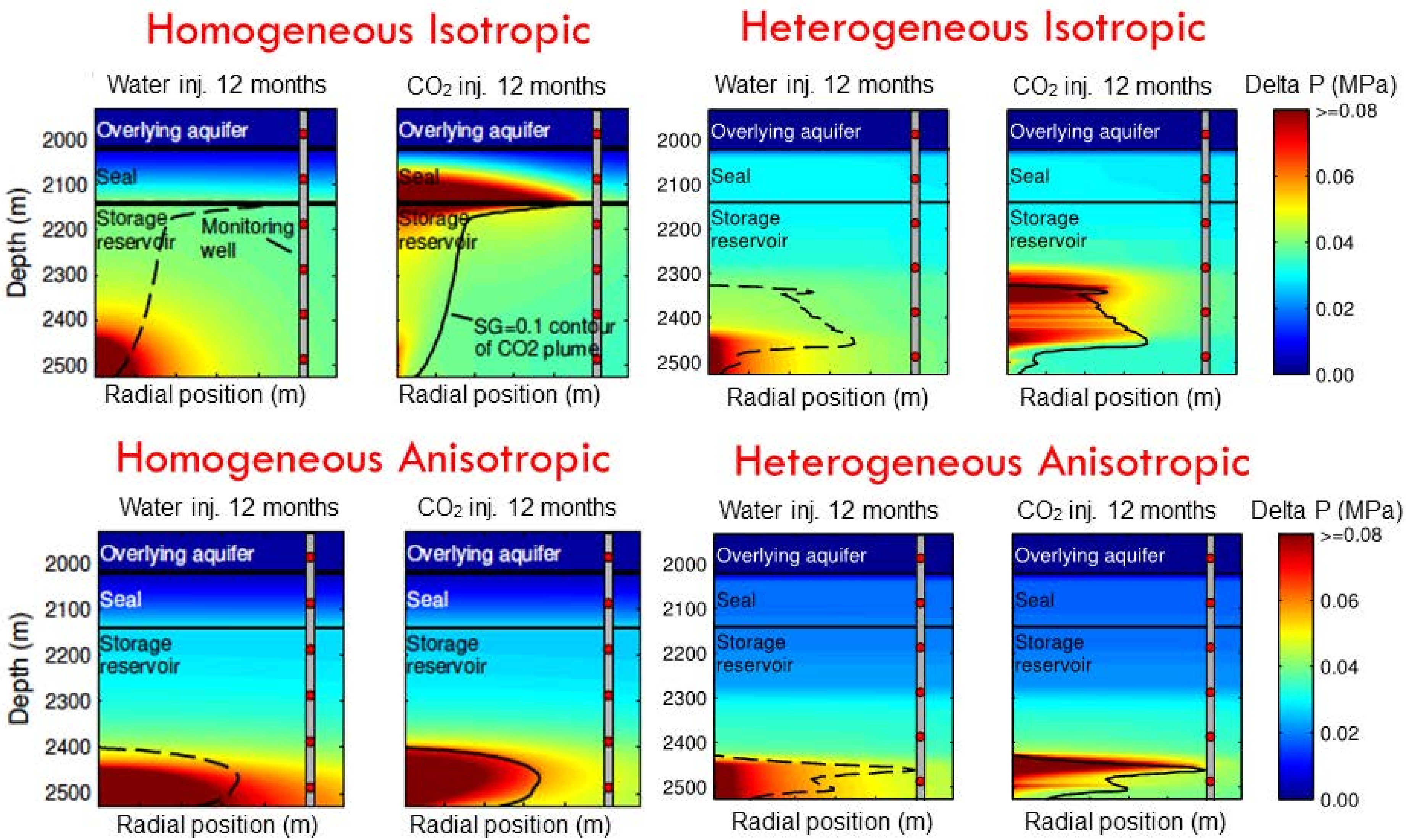



## Heterogeneous, anisotropic scenario



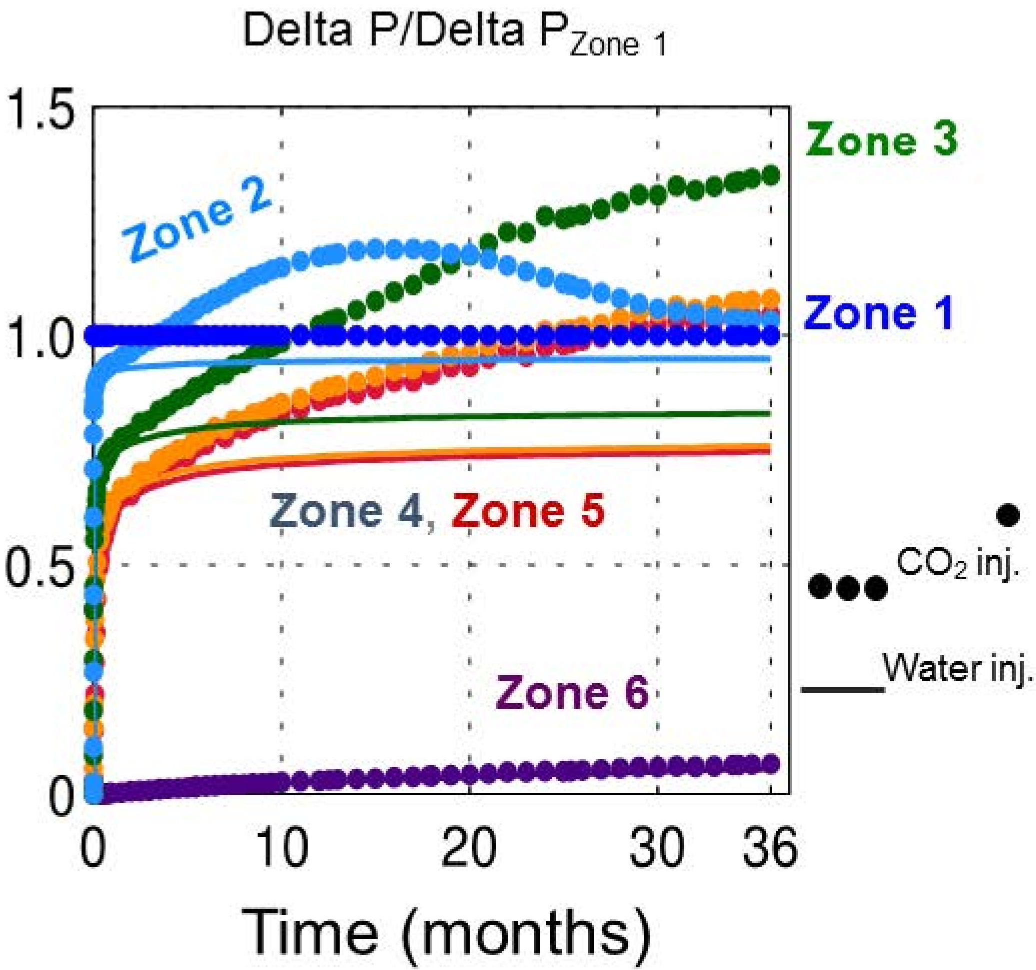
# Pressure Buildup Is Controlled By Reservoir Heterogeneity and Isotropy





# Pressure Transient Behavior Diagnoses Height of the Plume

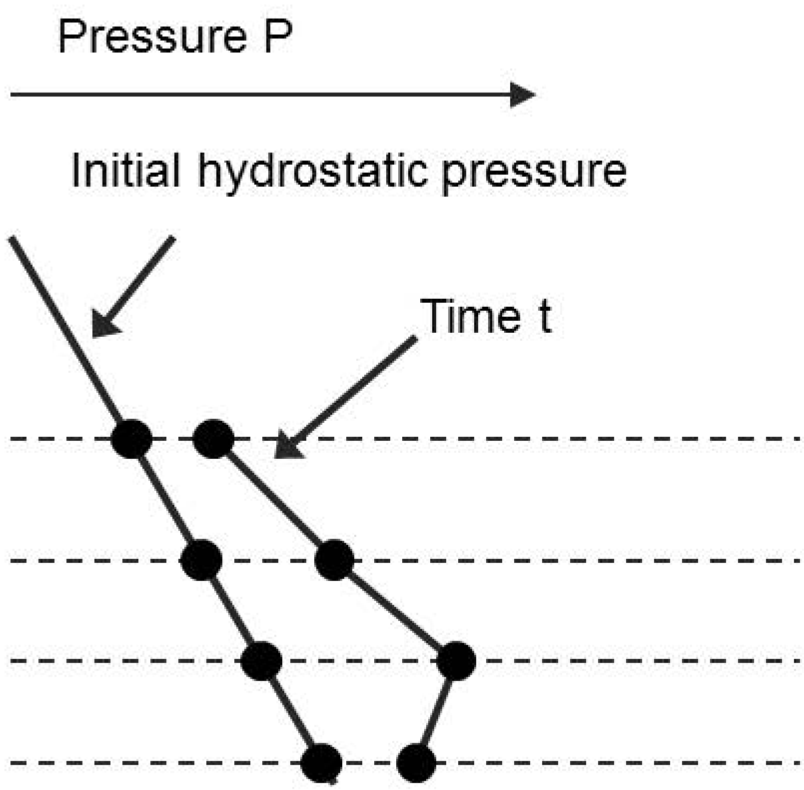


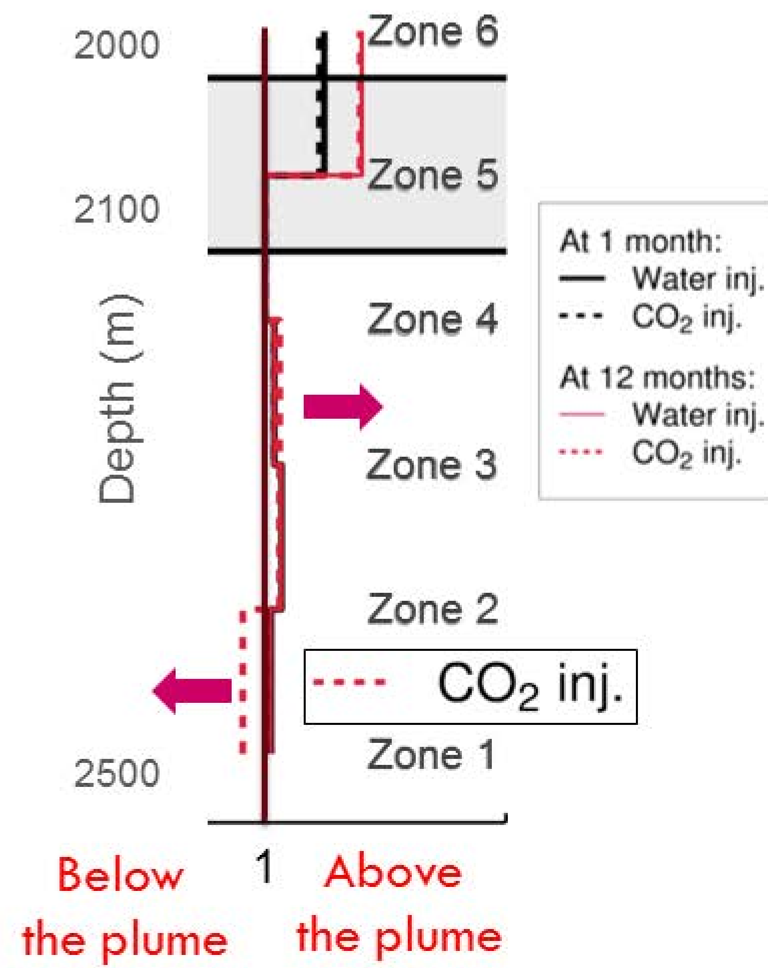



- Pressure buildups deviate from the behavior for water injection
- Pressure decreases indicate that the $CO_2$ plume has passed above the monitoring zone

# Vertical Pressure Gradients Diagnose Height of the Plume

Vertical pressure gradients normalized to the initial hydrostatic gradient



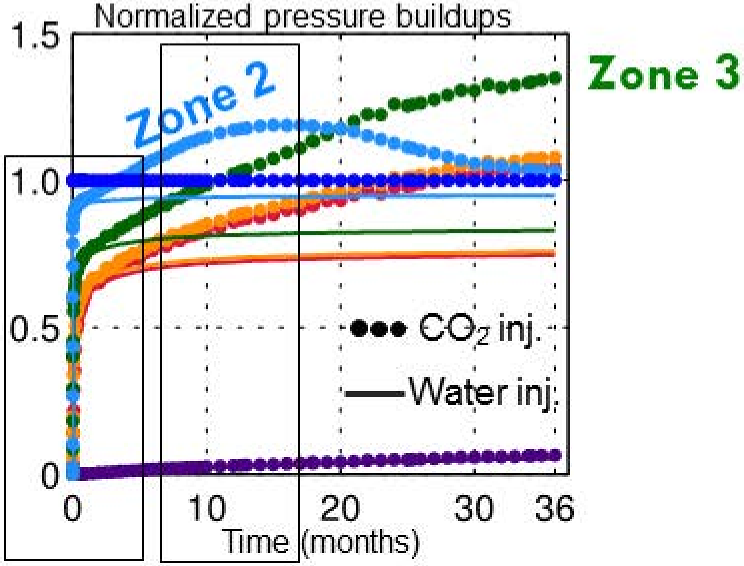
# Diagnostics: Summary

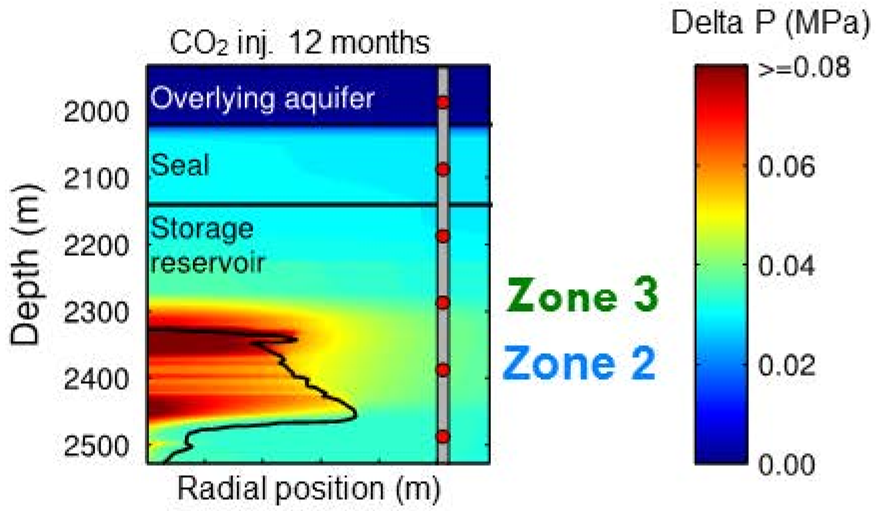


- Multilevel pressure transients provide real-time, continuous information on $CO_2$ plume migration

- At early time:
  Information on reservoir structure

- At later times:
  Diagnostic of height of $CO_2$ plume in reservoir

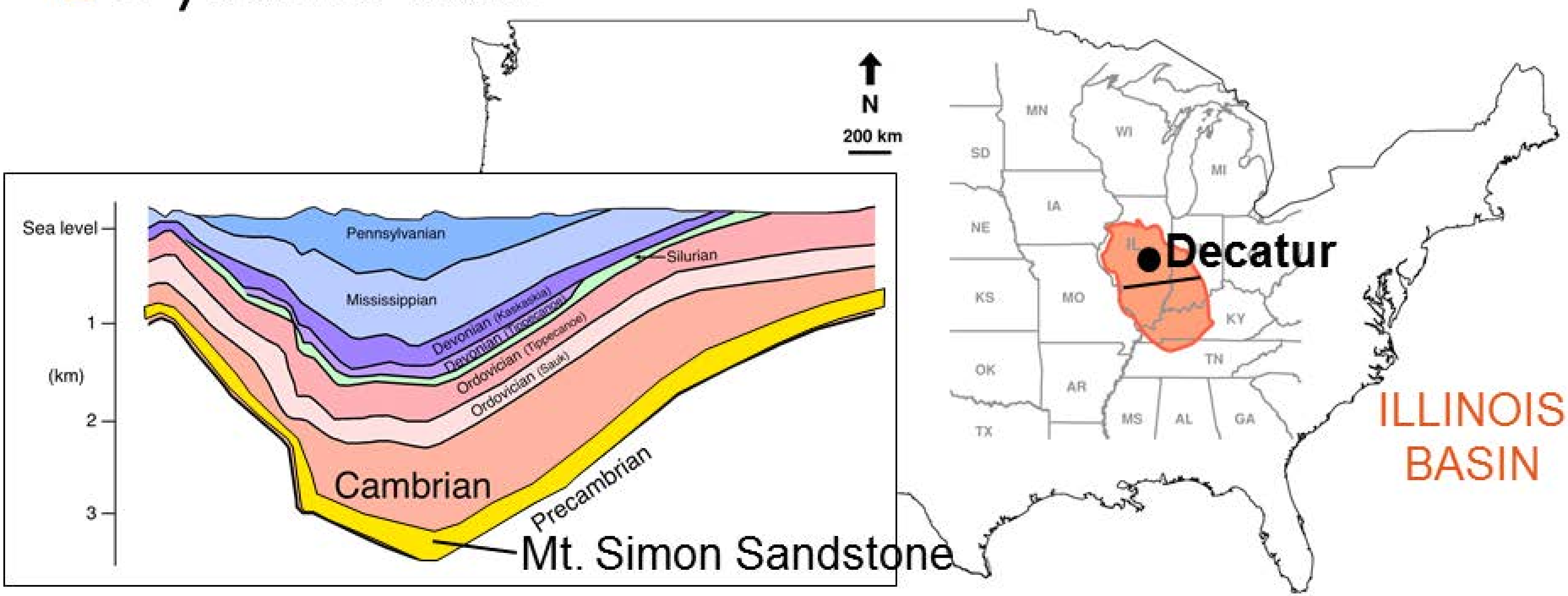


# Application to the Illinois Basin Decatur Project (IBDP)



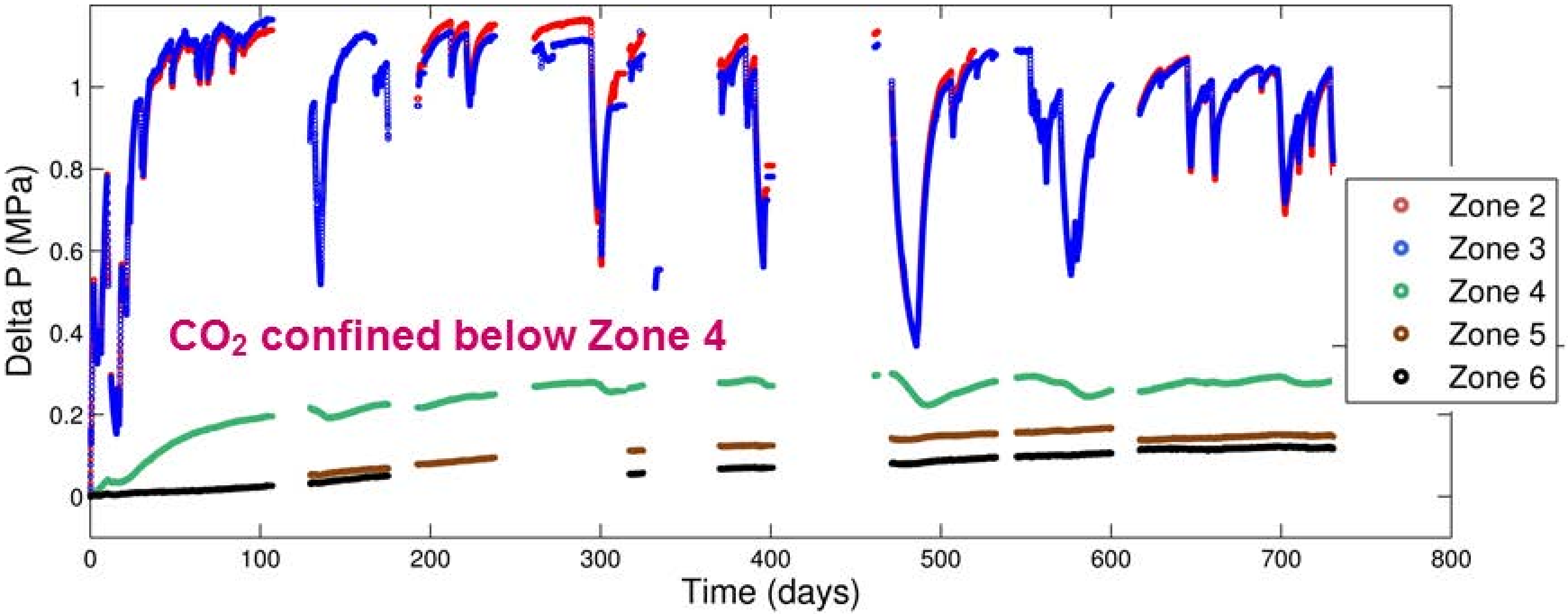
- 1 million metric tons $CO_2$ over 3 years
- 2 years of data



# Pressure Buildup Data



Pressure buildup at Zones 2 through 6 (variable inj. rate)



# History Matched Multilevel Pressure Transient Data



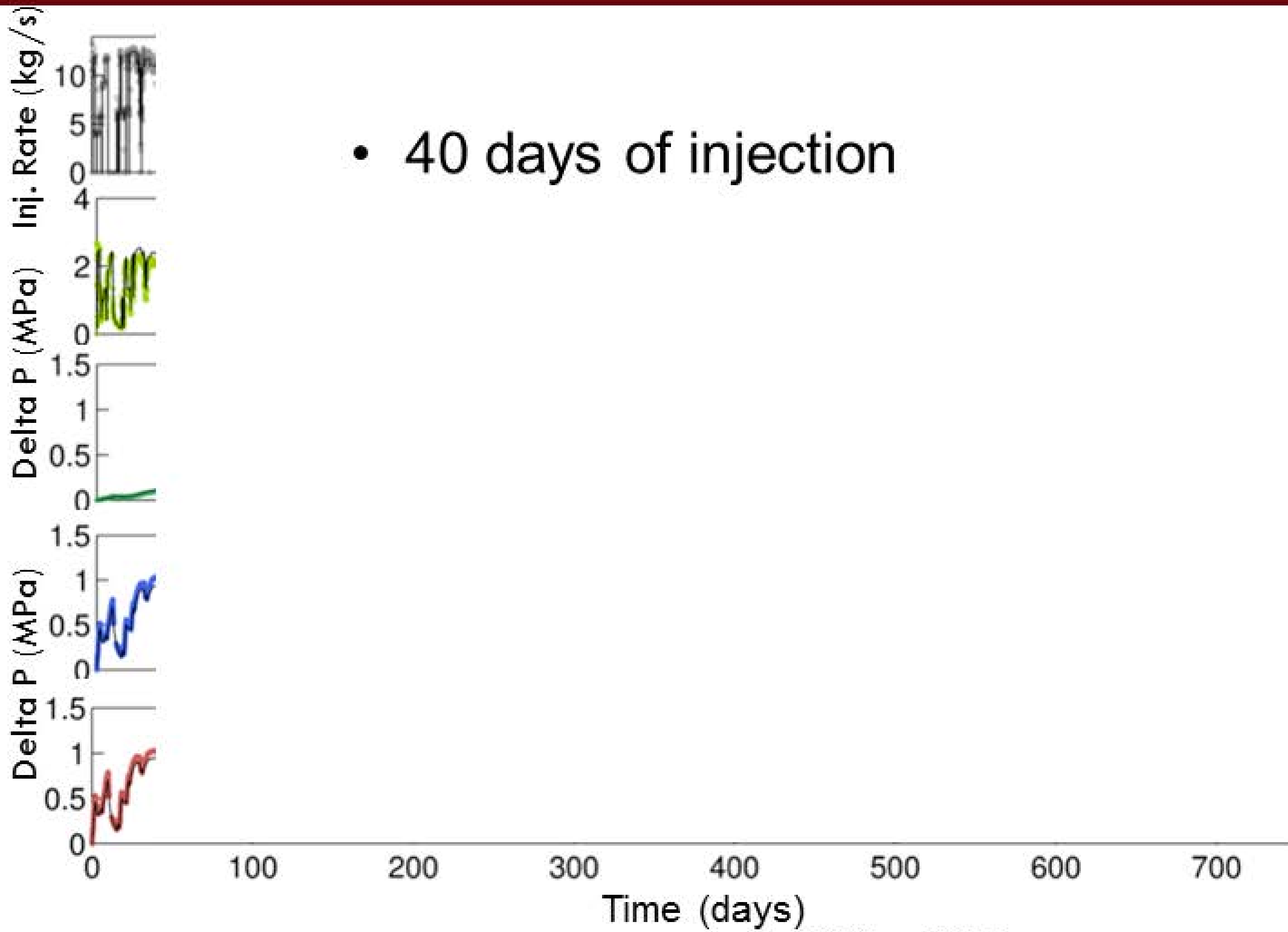
$CO_2$ inj. rate:

BHP (inj. well):

Zone 4:

Zone 3:

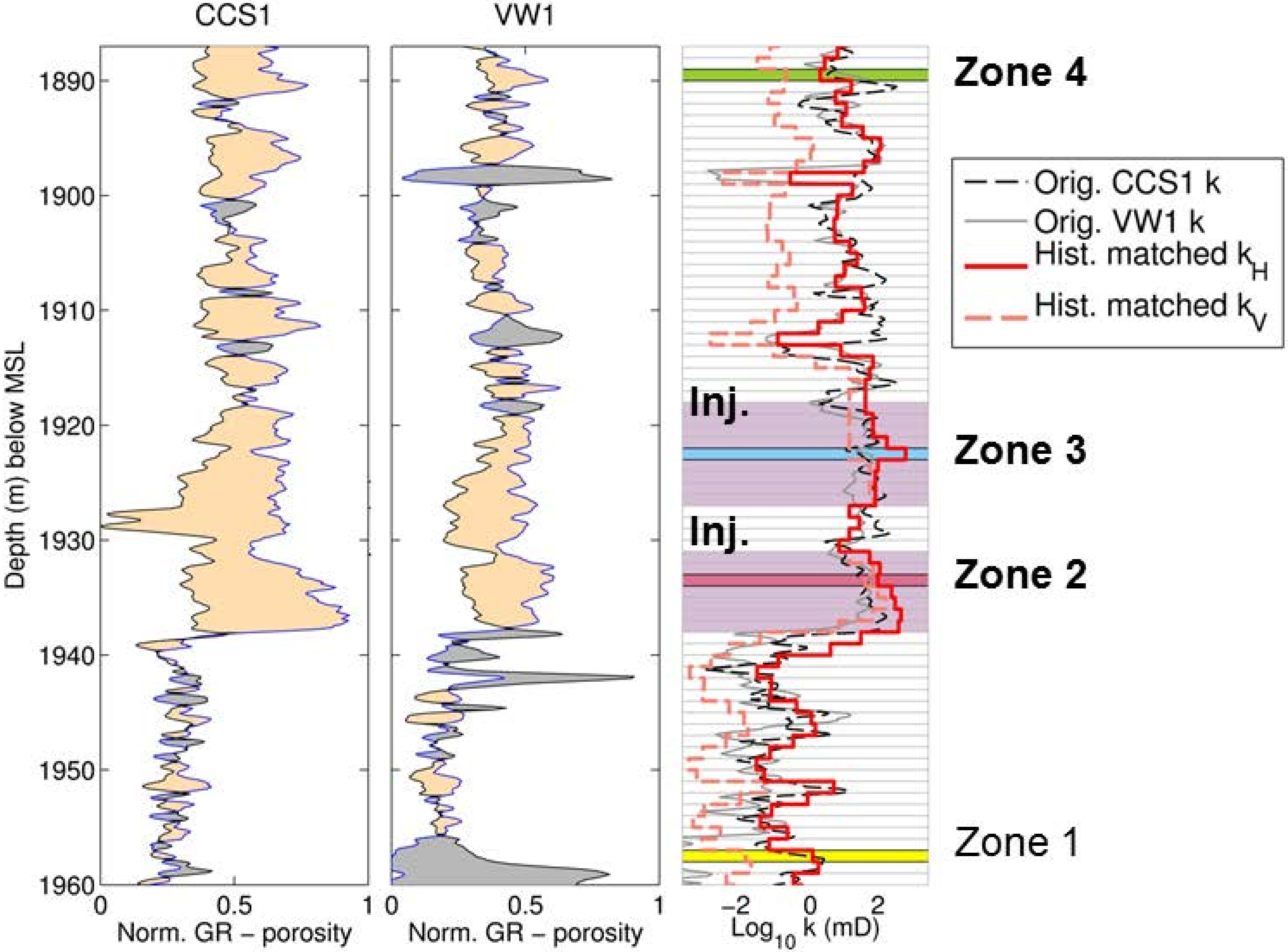
Zone 2:




- 40 days of injection

# History Matched Permeability

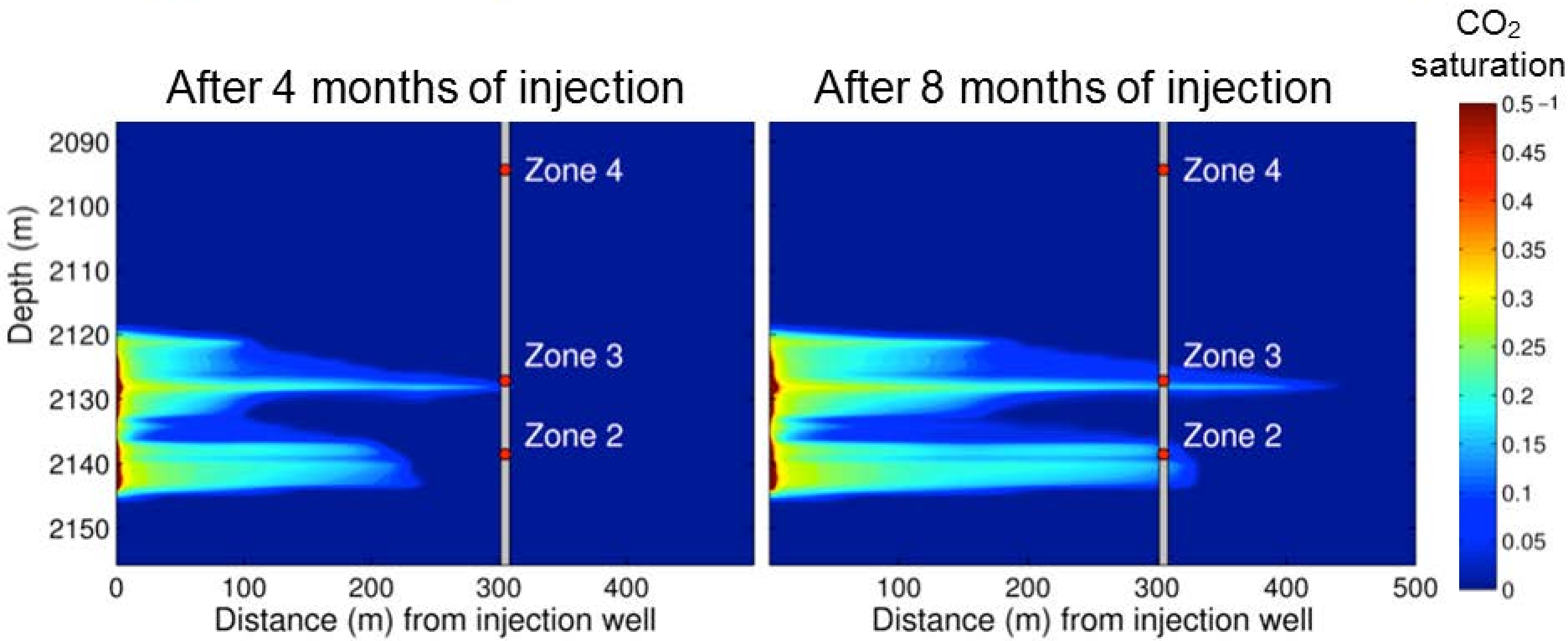




# History Matching: Predicted $CO_2$ Plume Migration

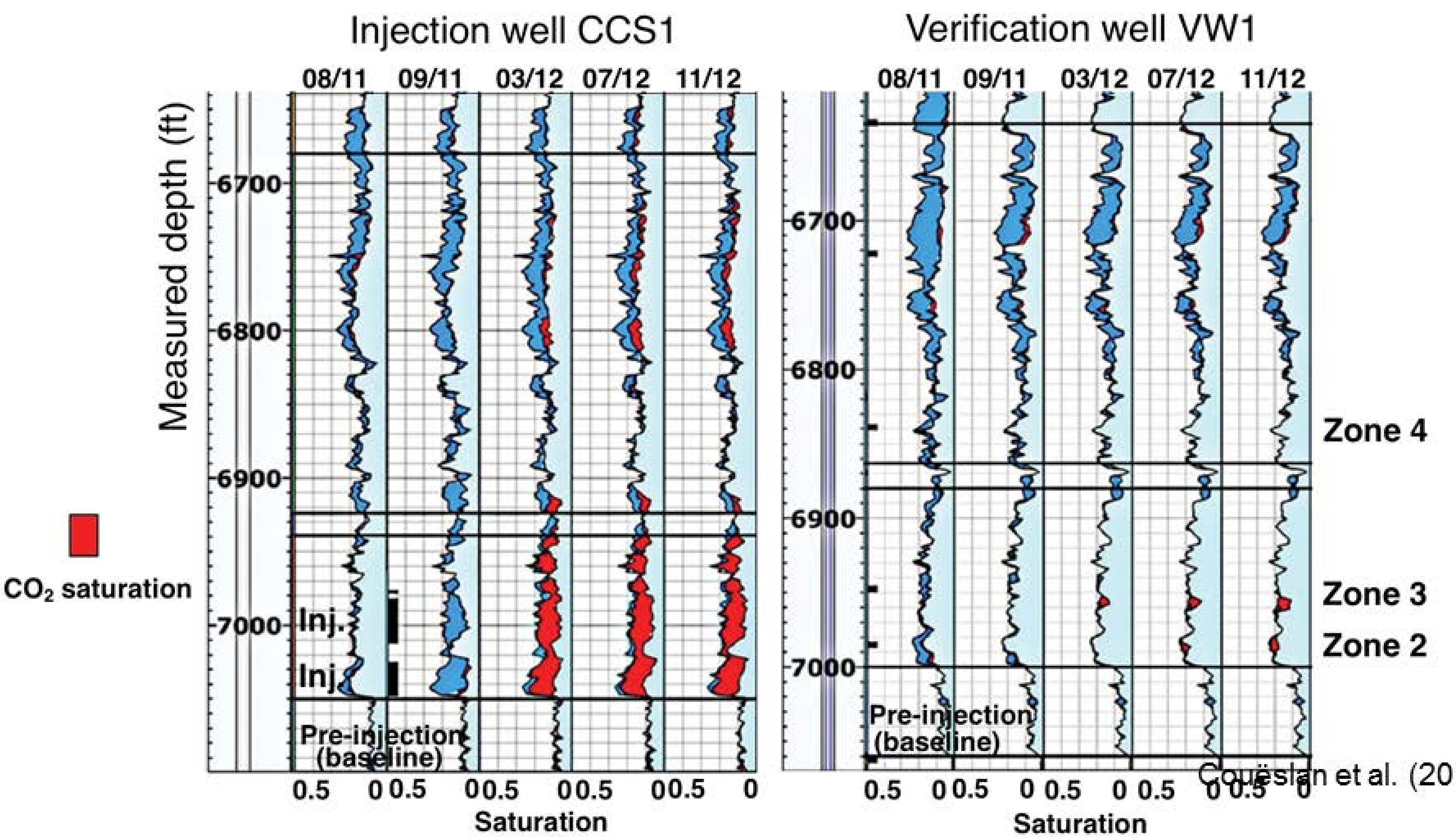


## Agrees with diagnostics and reservoir saturation tool logs



# Measured $CO_2$ Saturation



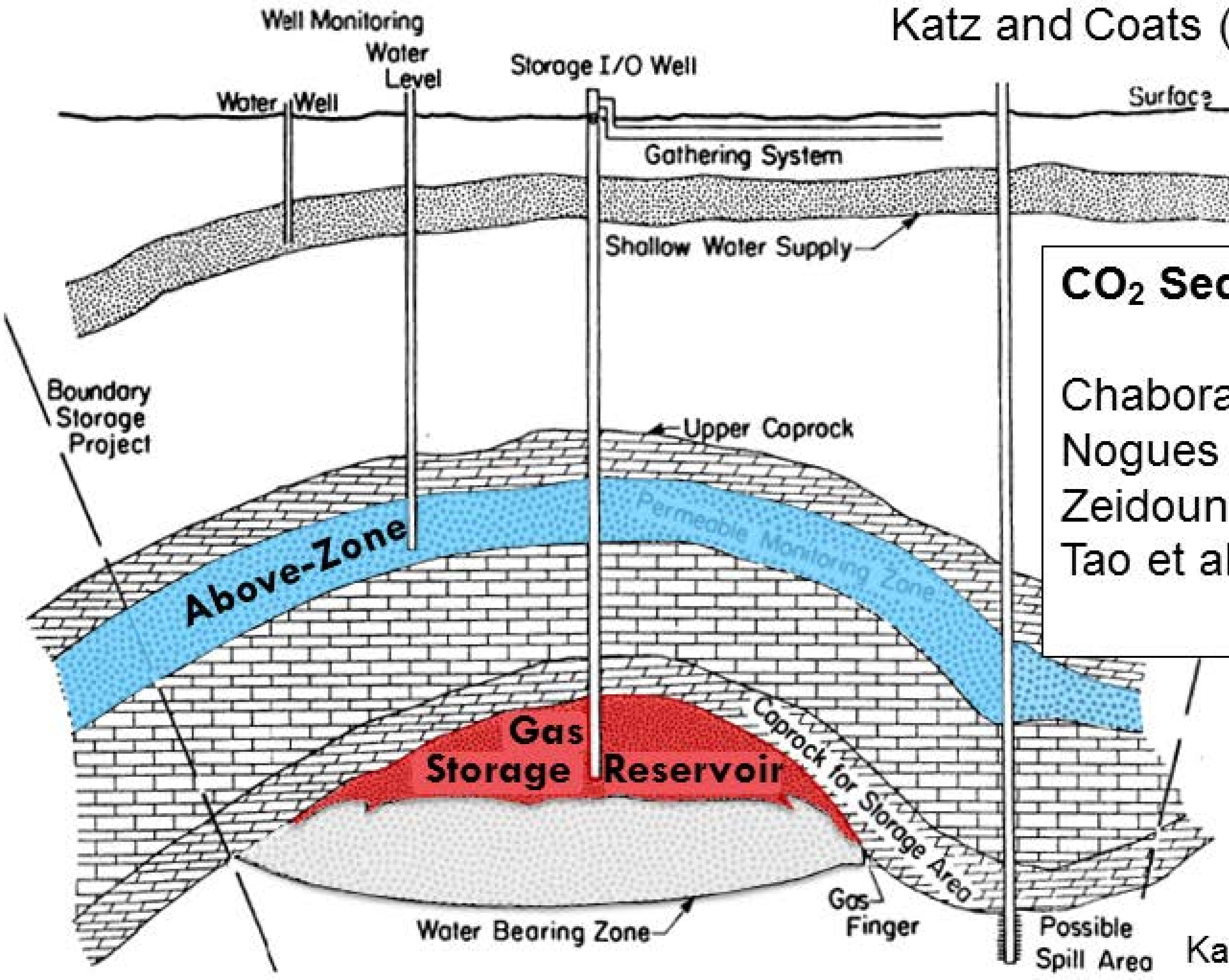



Couëslan et al. (2014)

# Above-Zone Pressure Monitoring



Katz and Coats (1968)



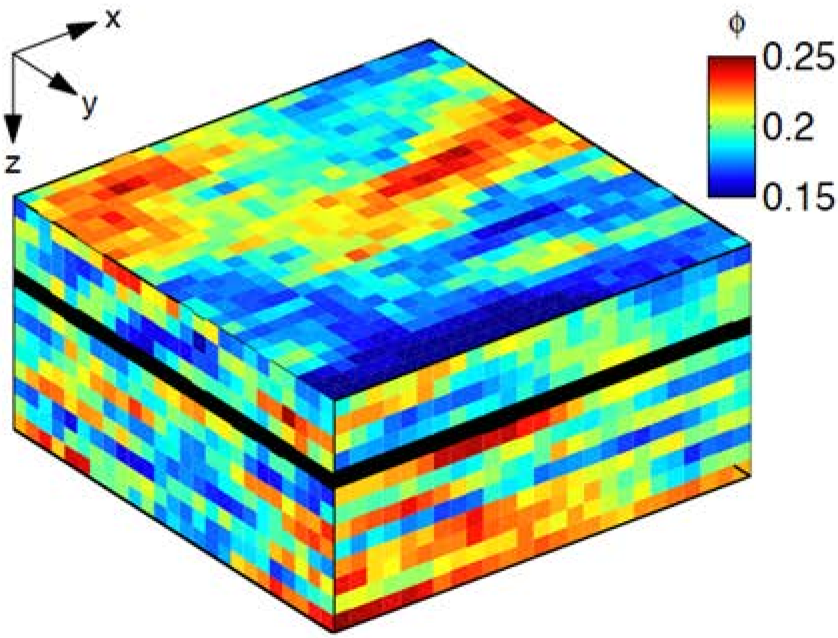

**$CO_2$ Sequestration:**

Chabora (2009)
Nogues et al. (2011)
Zeidouni et al. (2011)
Tao et al. (2012)

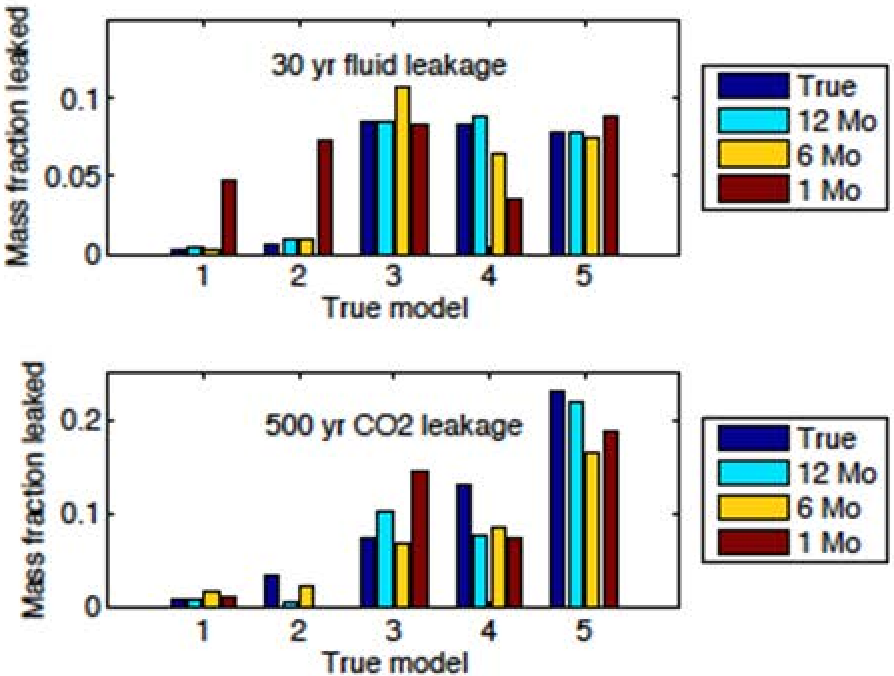
Katz (1971)

# Above-Zone Monitoring in Heterogeneous Aquifers






Stochastic model of geological heterogeneity.

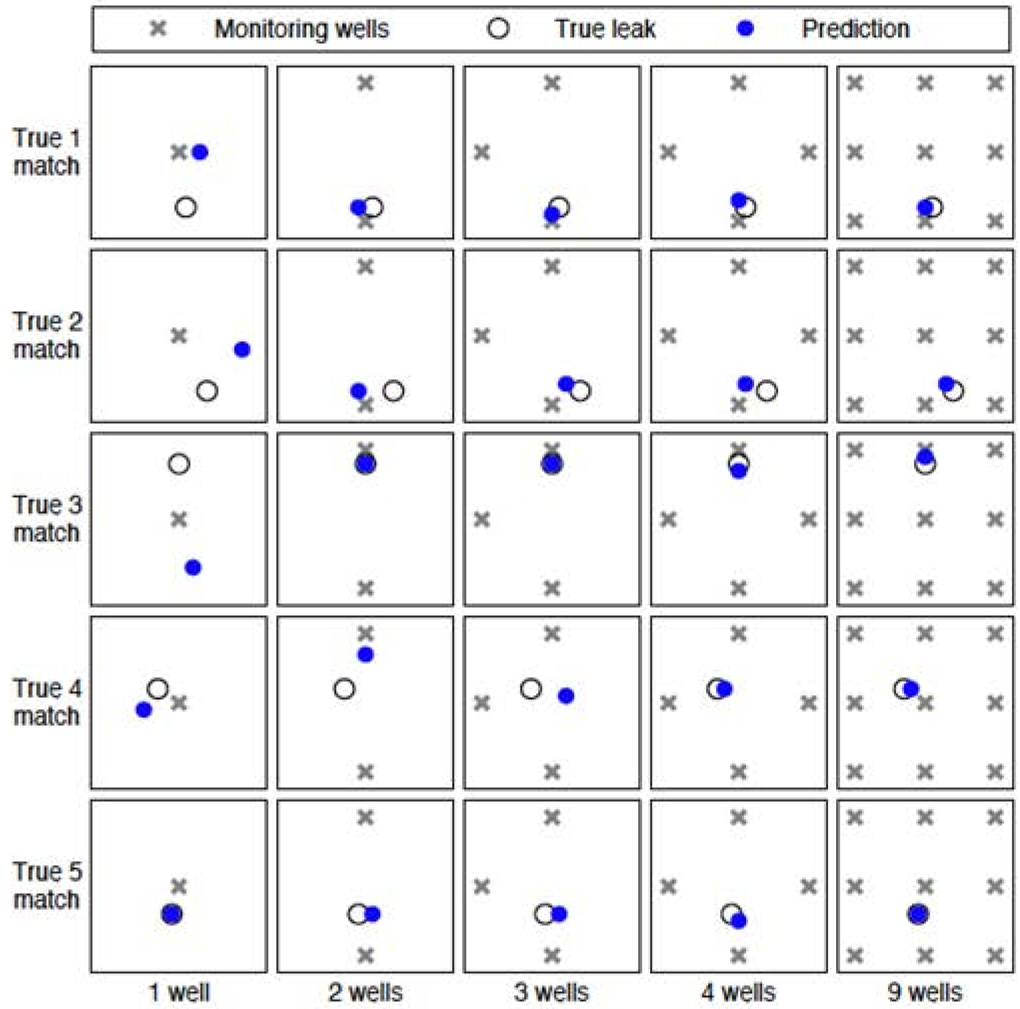


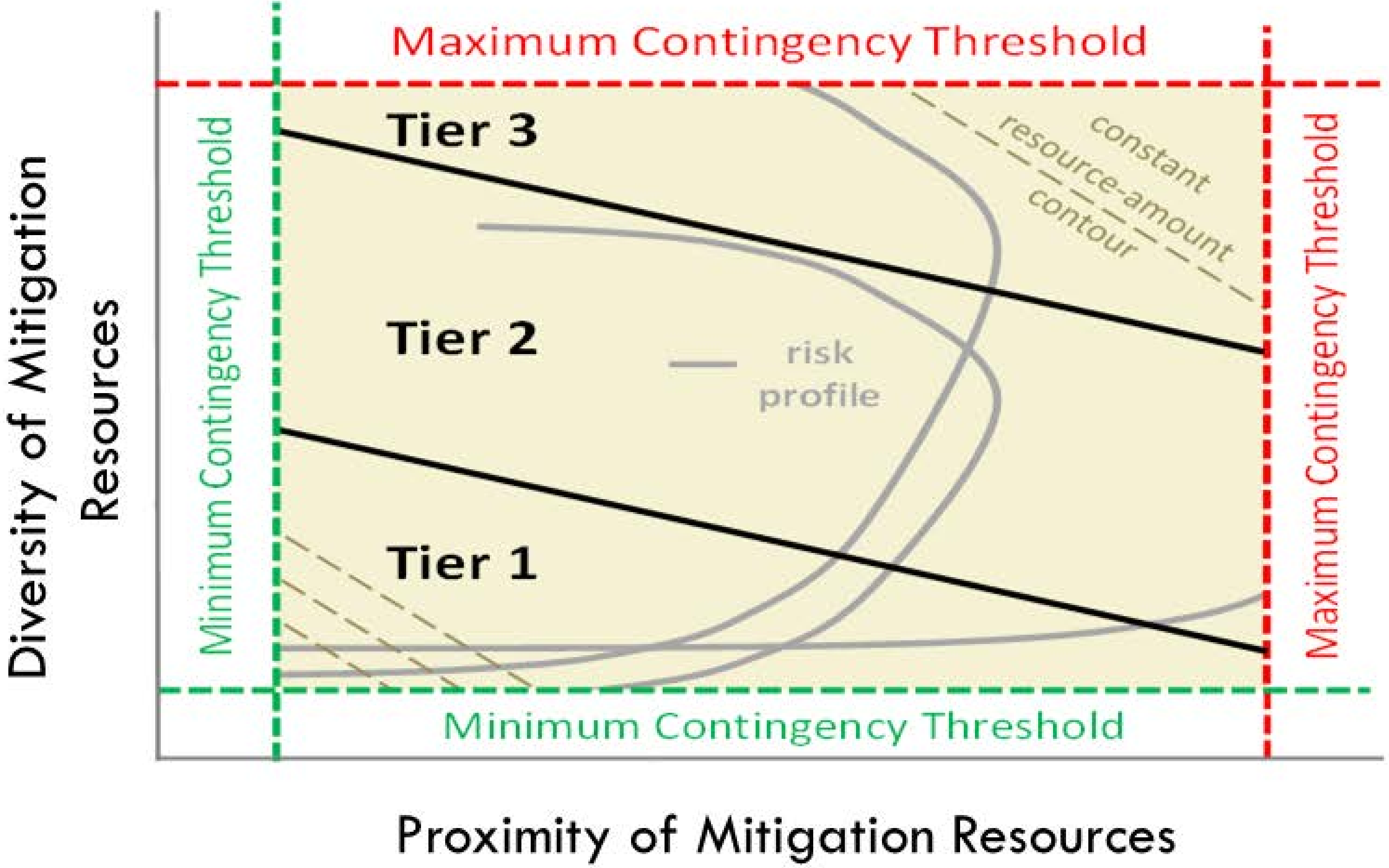

Leakage prediction using 9 monitoring wells in the above-zone aquifer.

D. Cameron, L. Durlofsky, and S.M. Benson, 2015. Assimilation of pressure data to locate and quantify leaks during carbon storage operations, submitted.

# Leakage location is possible with 3-4 monitoring wells





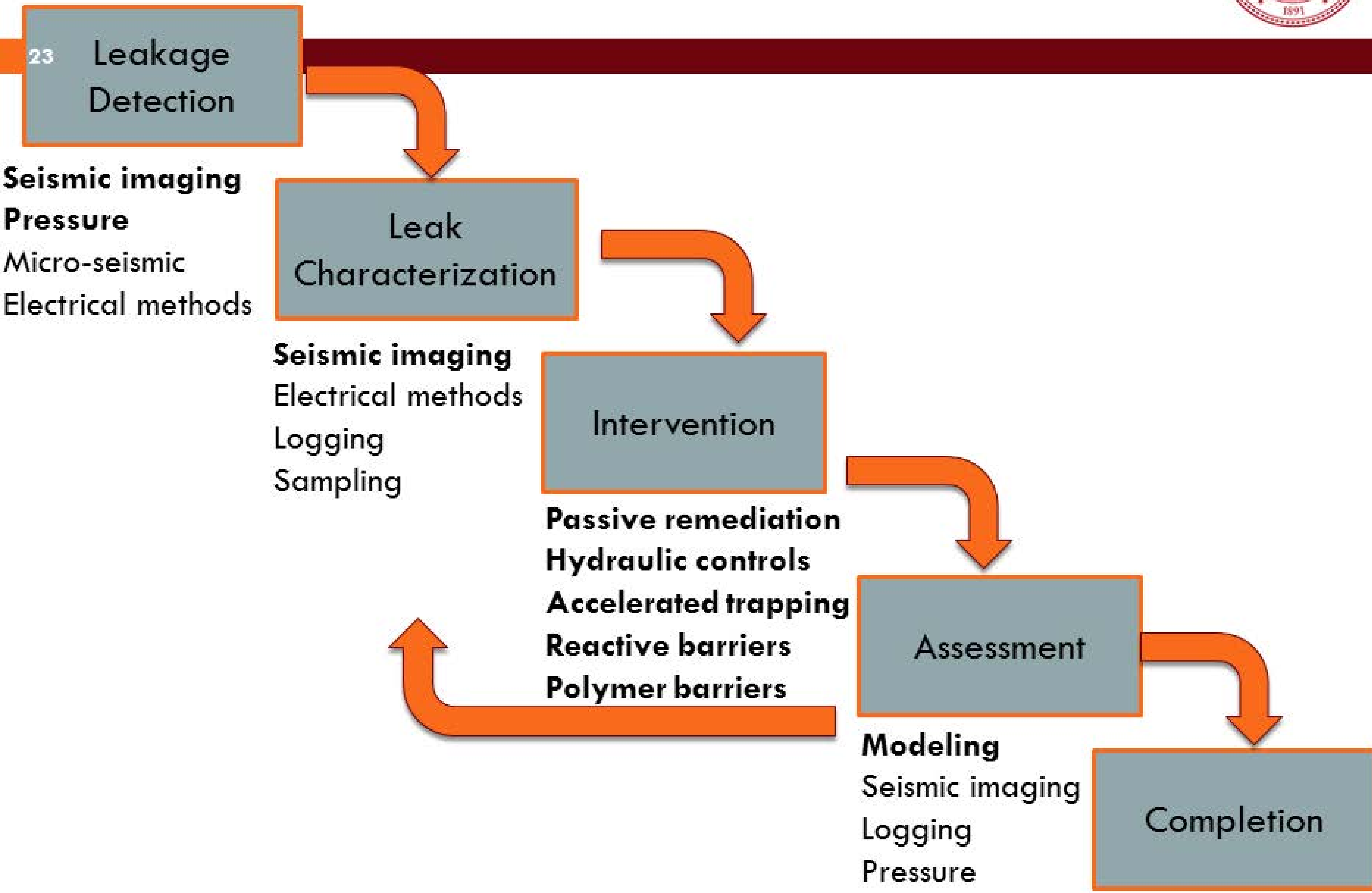




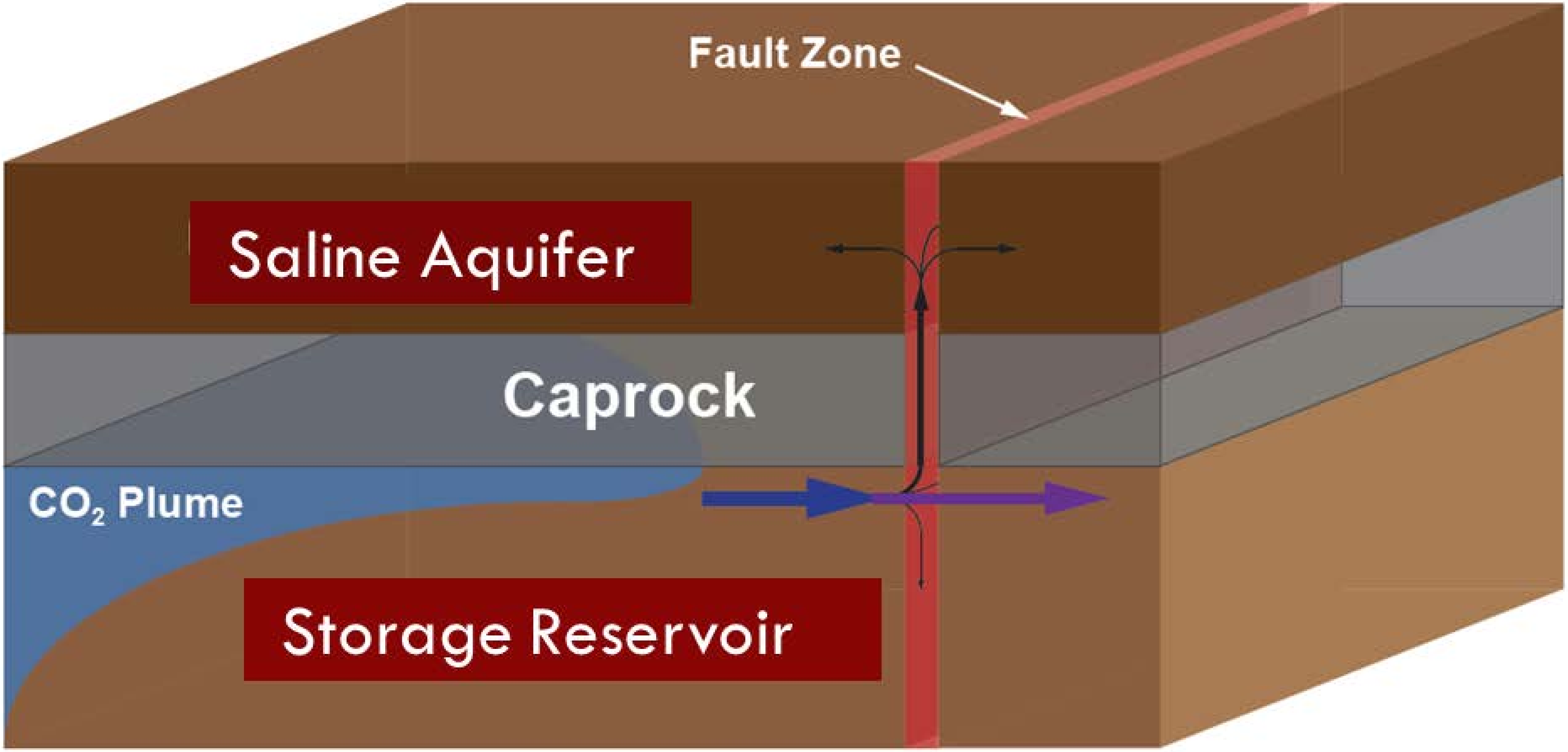

## Contingency Planning

# Leakage Detection and Intervention Workflow





# Study System For Evaluating Hydraulic Controls For Leaking Faults



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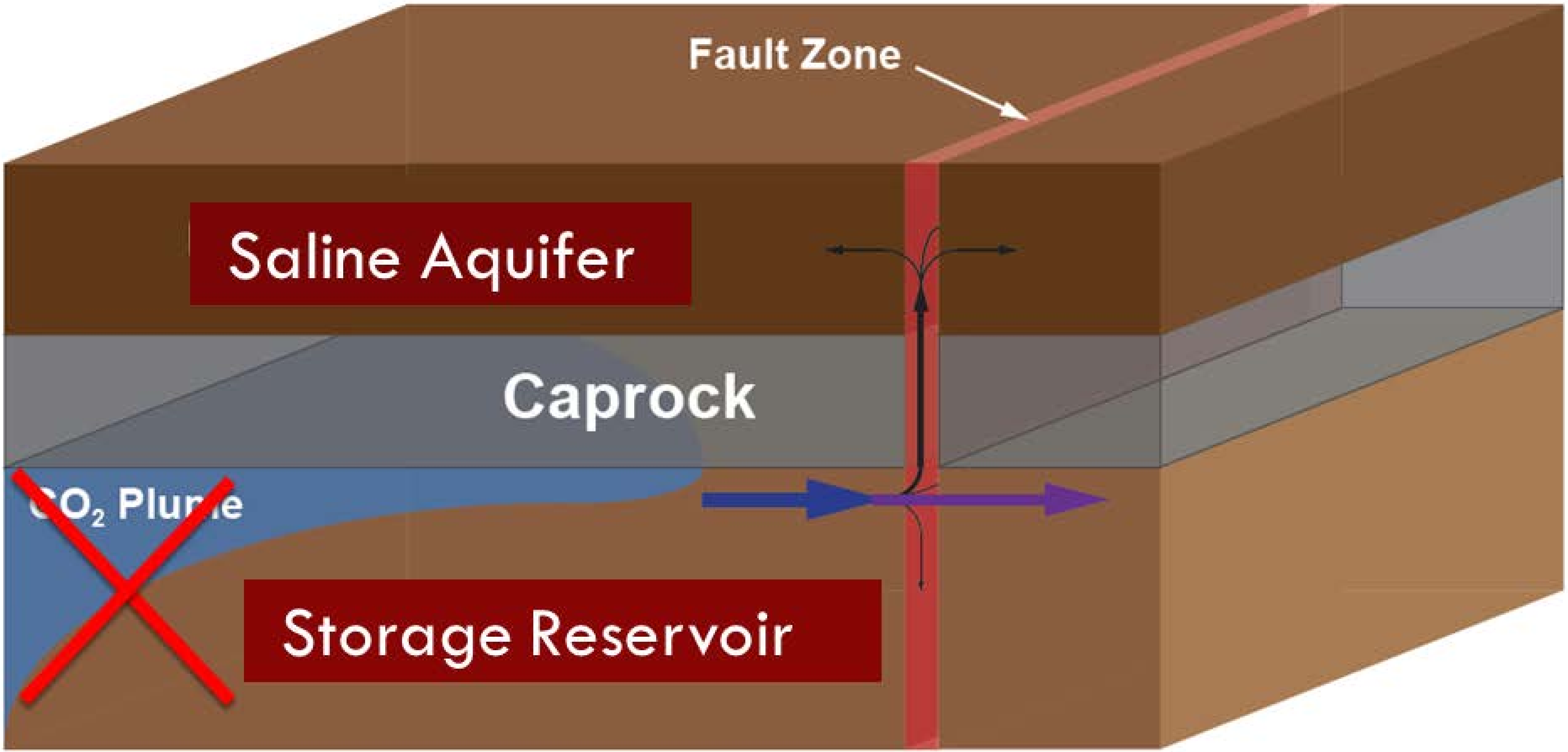
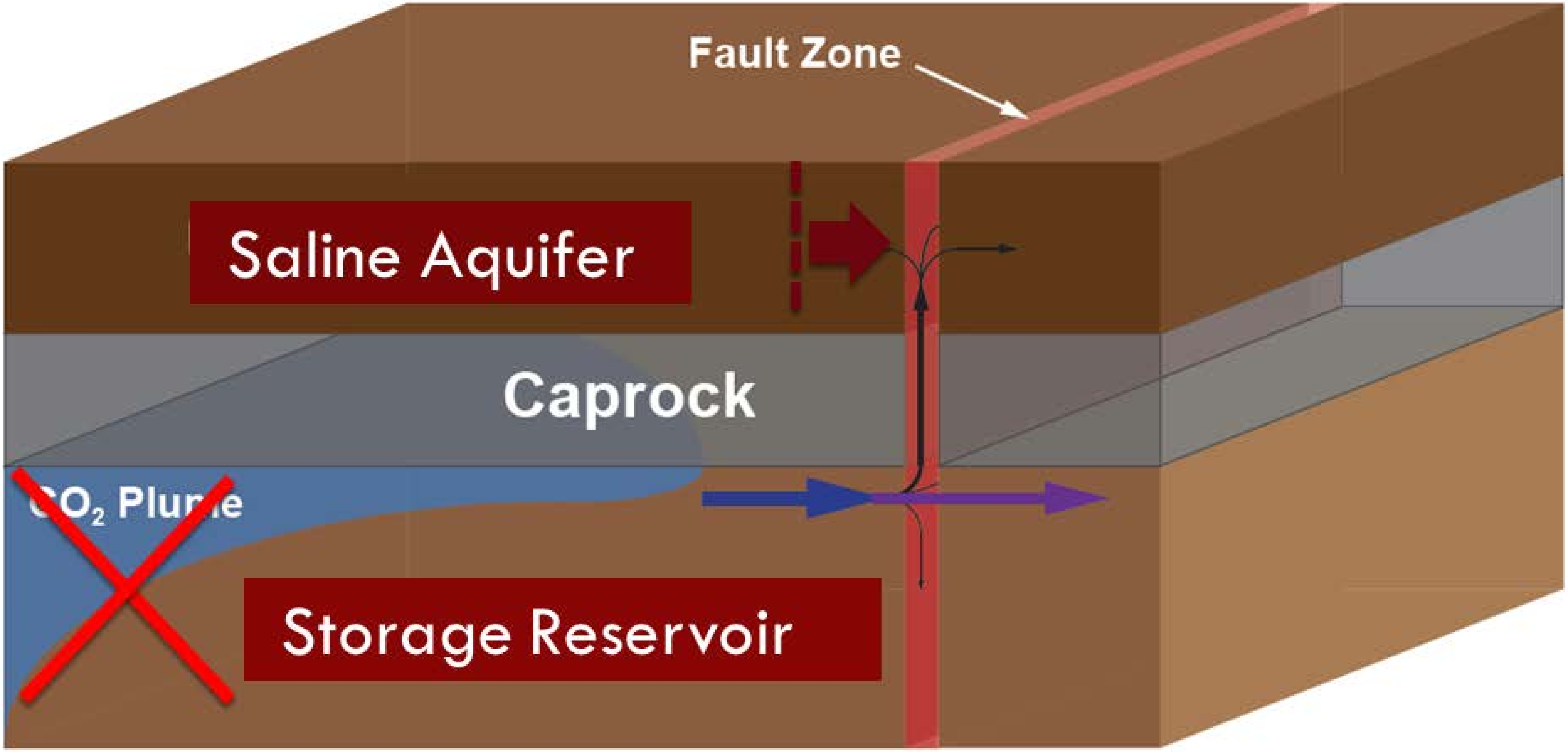


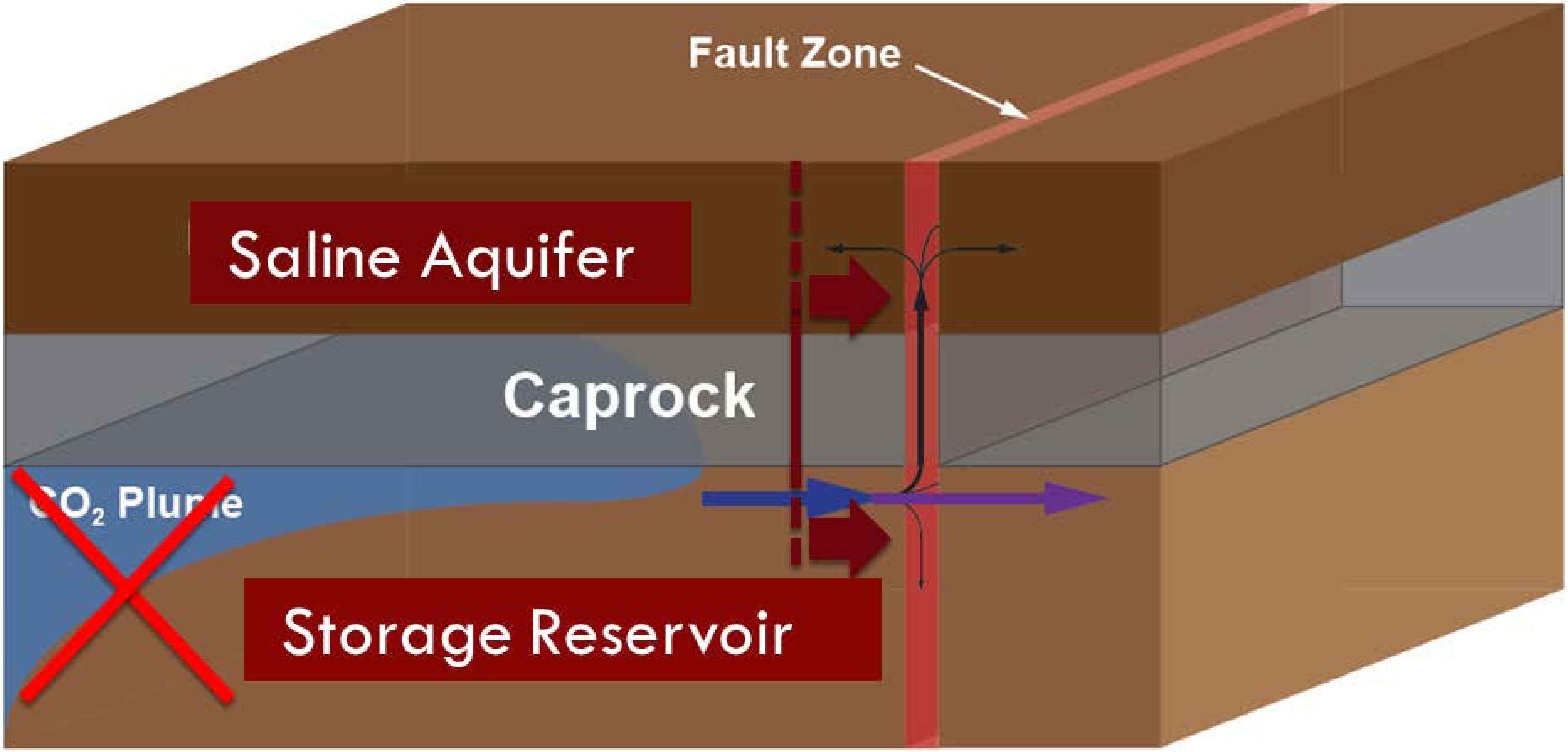

1. Shut off $CO_2$ injection near the fault

# Study System For Evaluating Hydraulic Controls For Leaking Faults



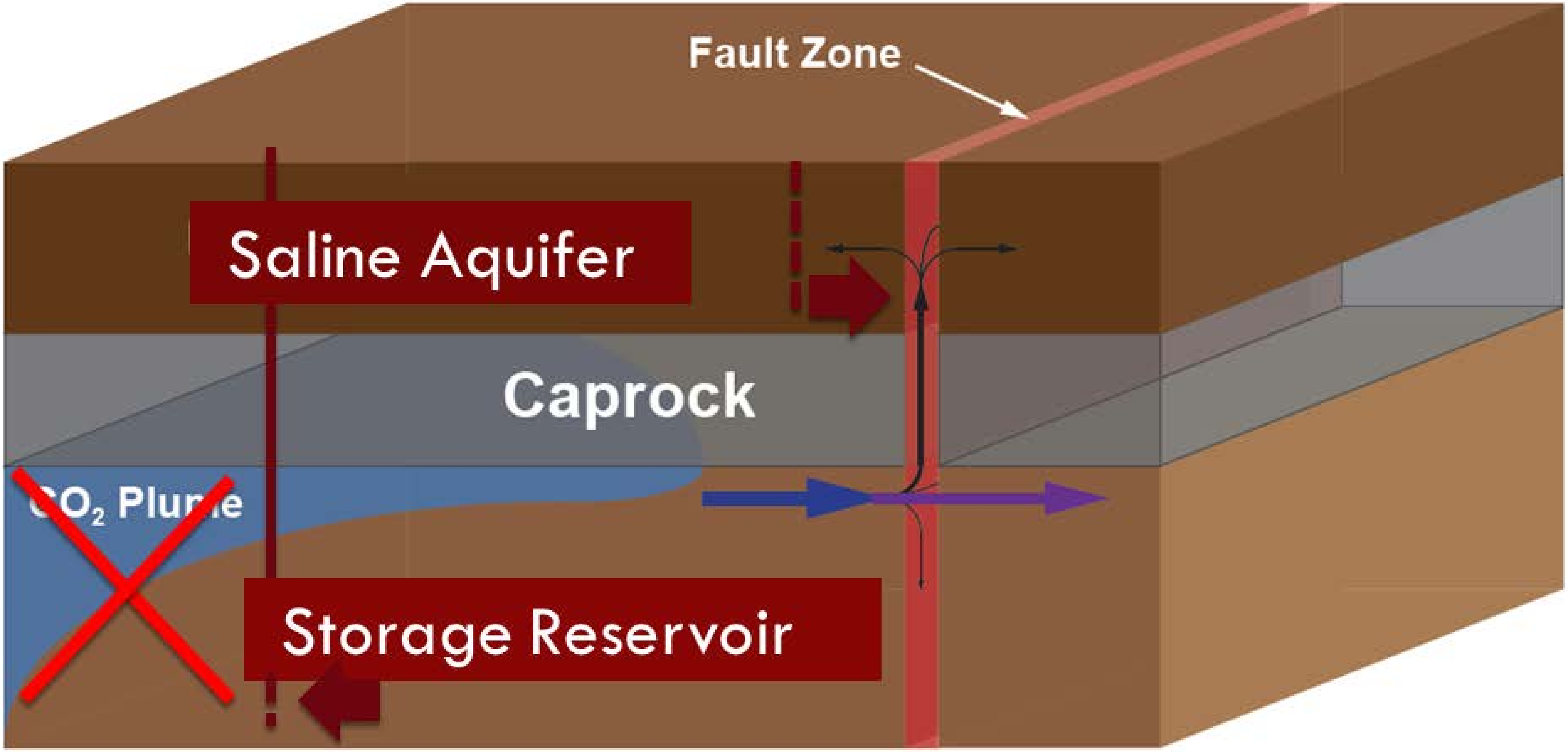

2. Water injection above the fault

# Study System For Evaluating Hydraulic Controls For Leaking Faults




3. Water injection above and below the fault

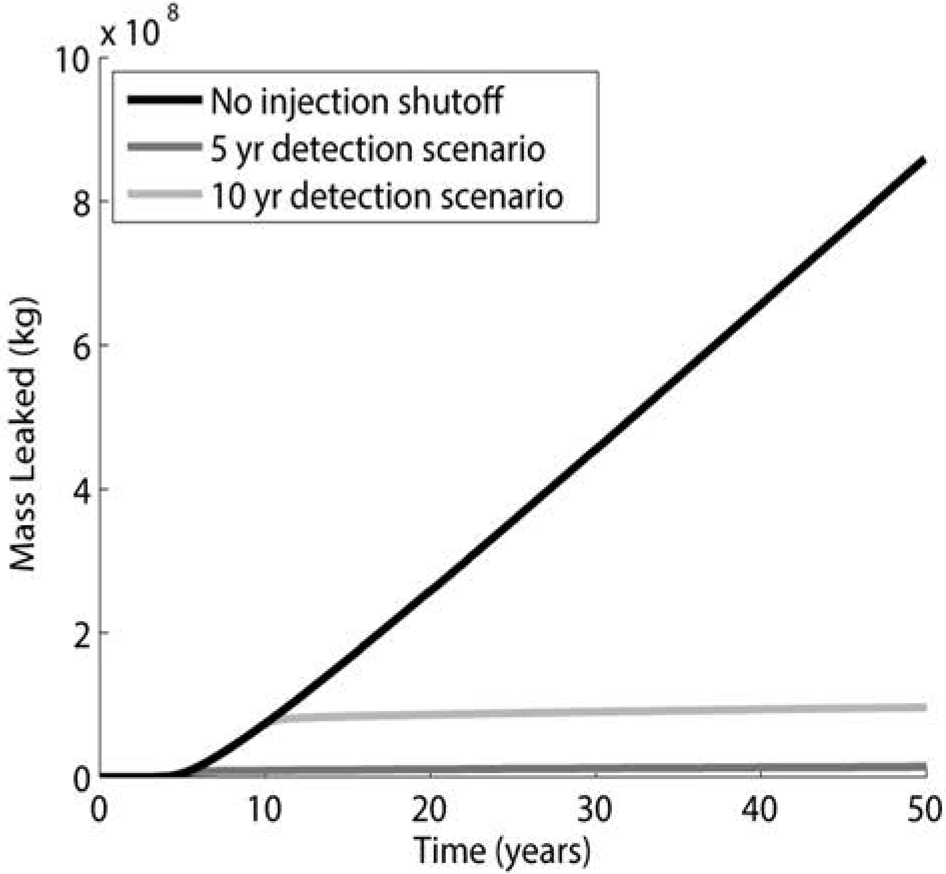
# Study System For Evaluating Hydraulic Controls For Leaking Faults



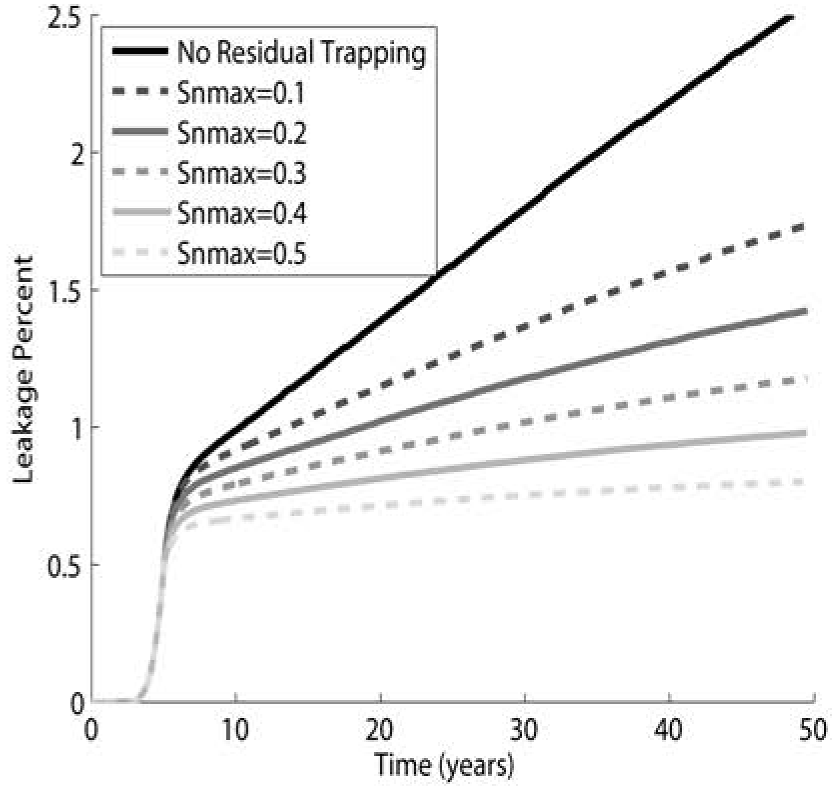

4. Water injection above the fault with water production

# Injection Shut-Off Rapidly Reduces Leakage





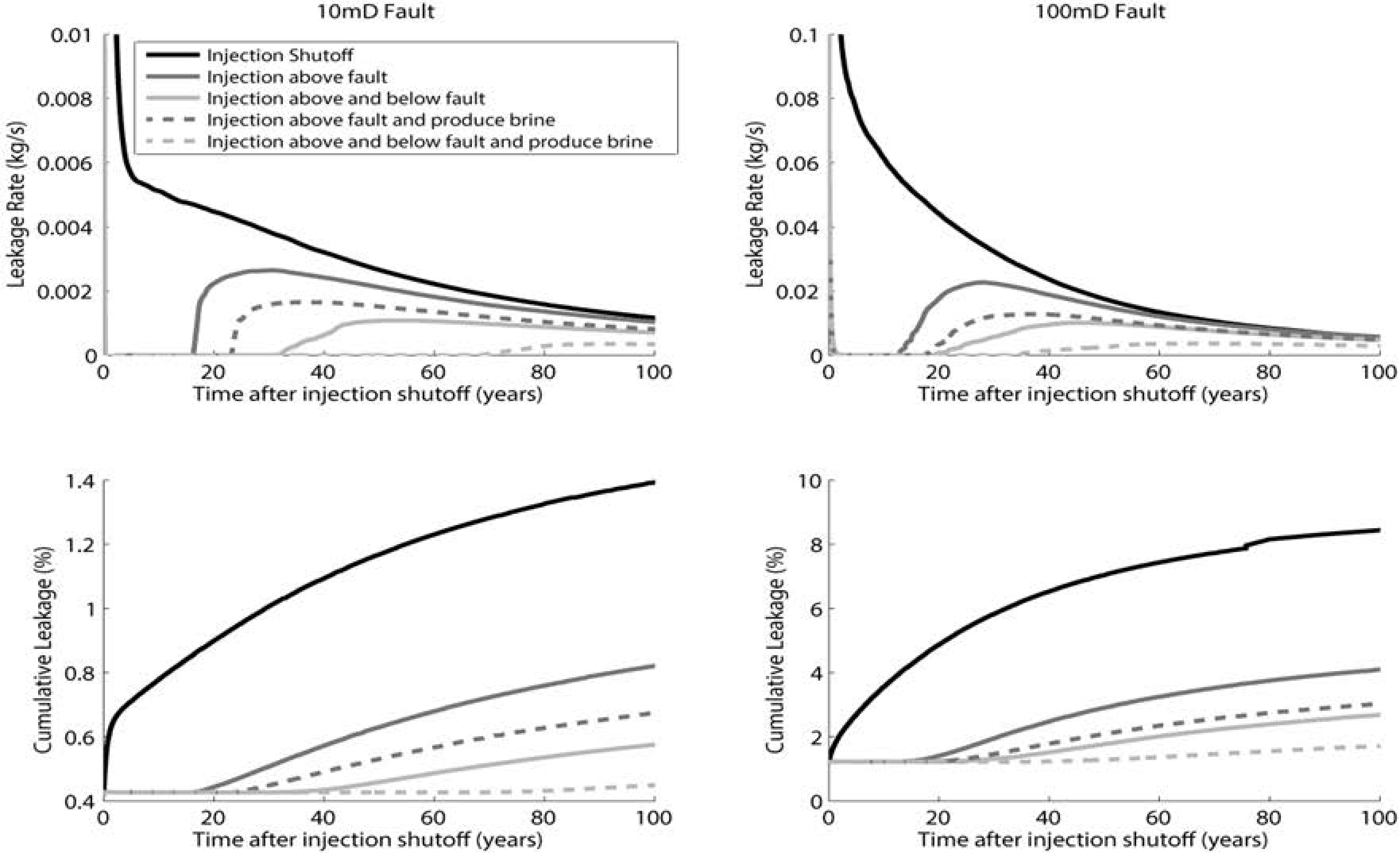

Leakage rates for the case with no residual trapping.




Influence of residual trapping on leakage rates.

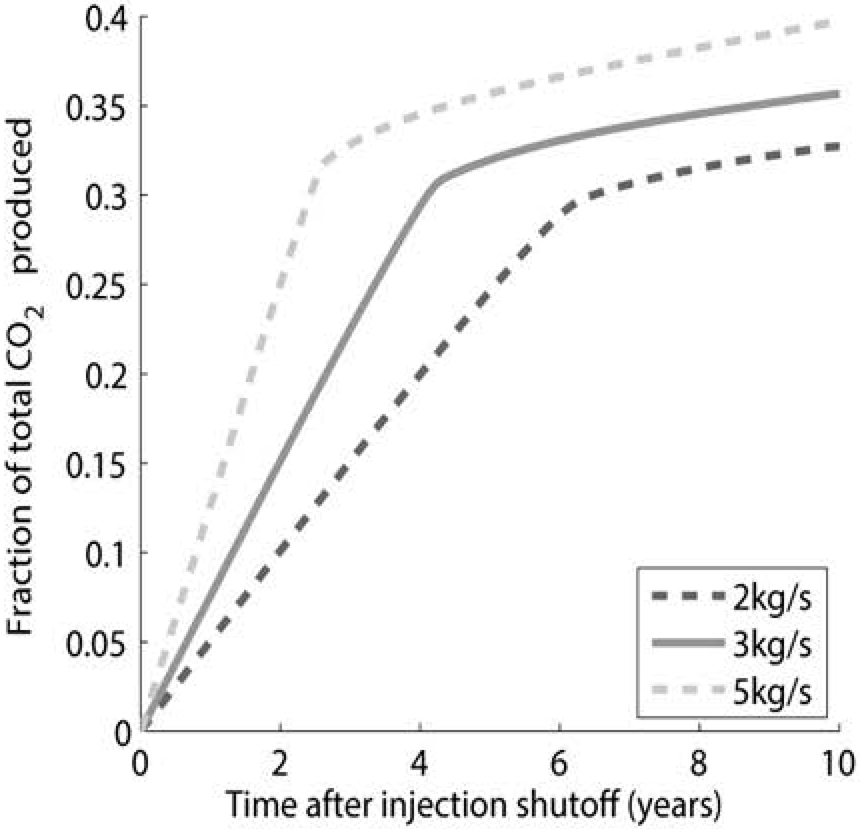
# Additional Hydraulic Controls Further Reduce Leakage

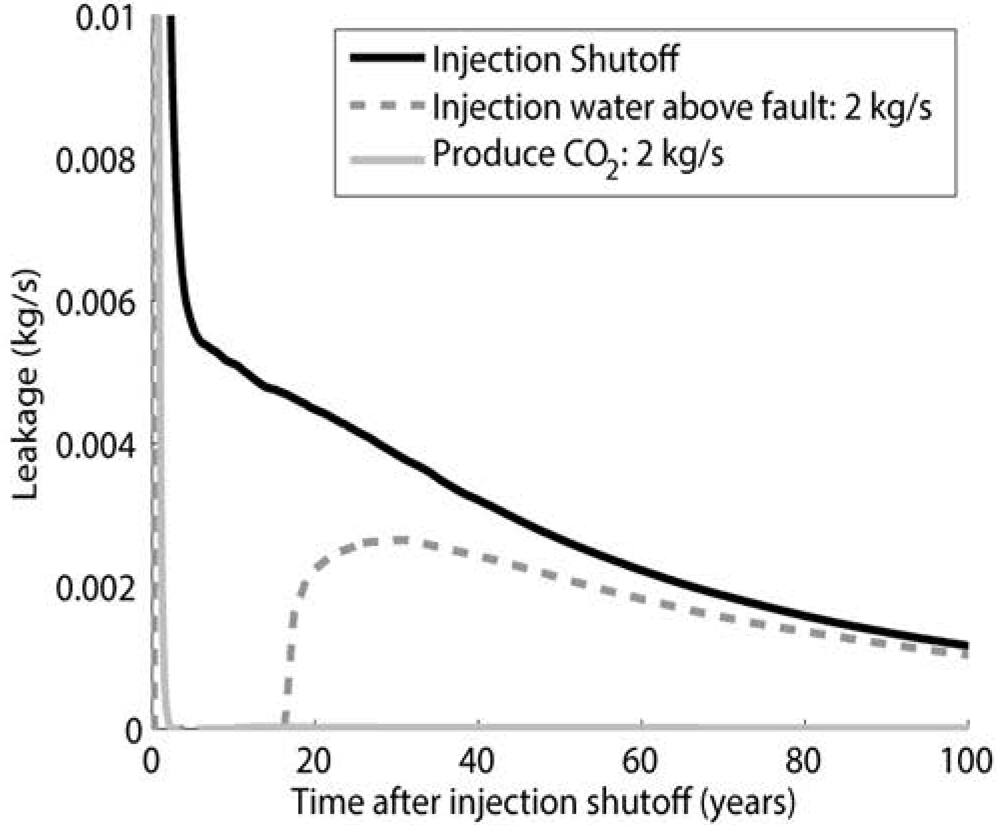




# Removing About 30% of the $CO_2$ Completely Stops Leakage

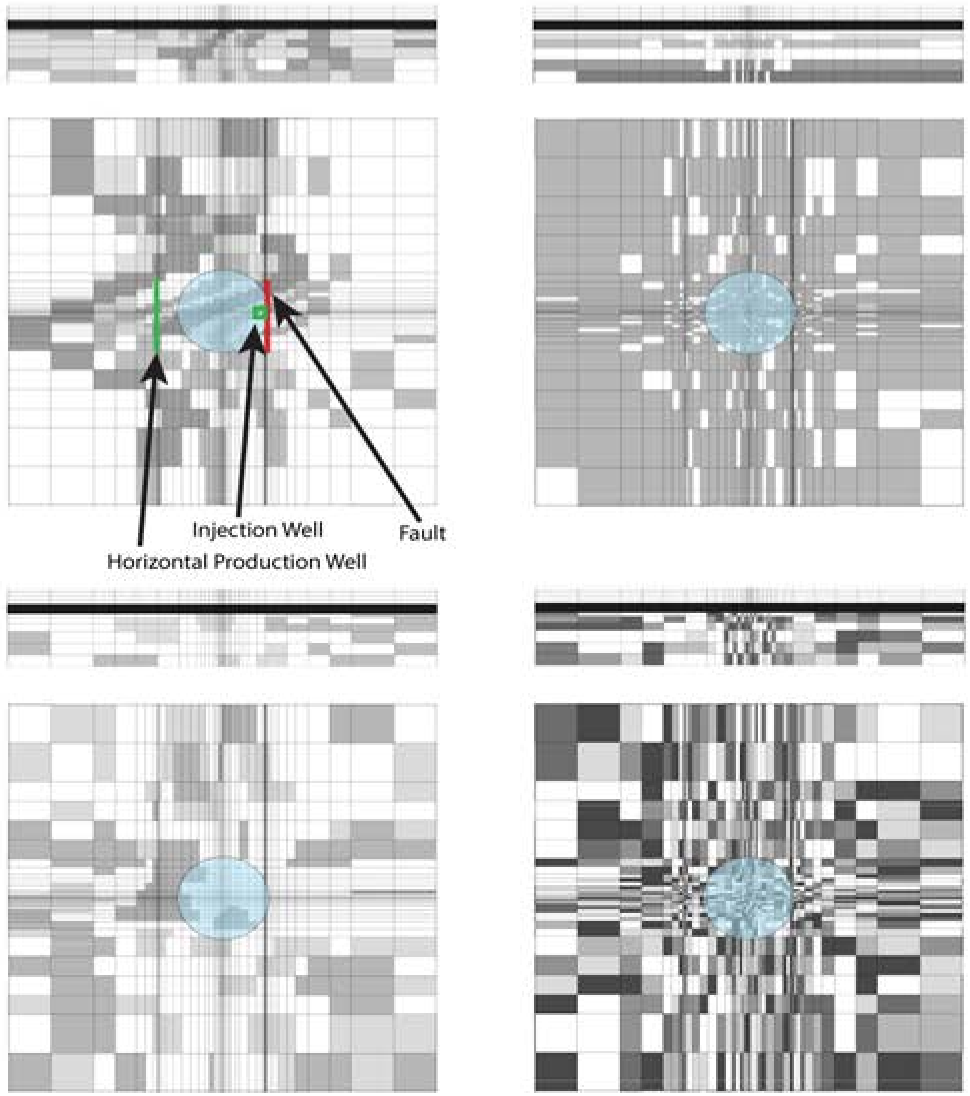




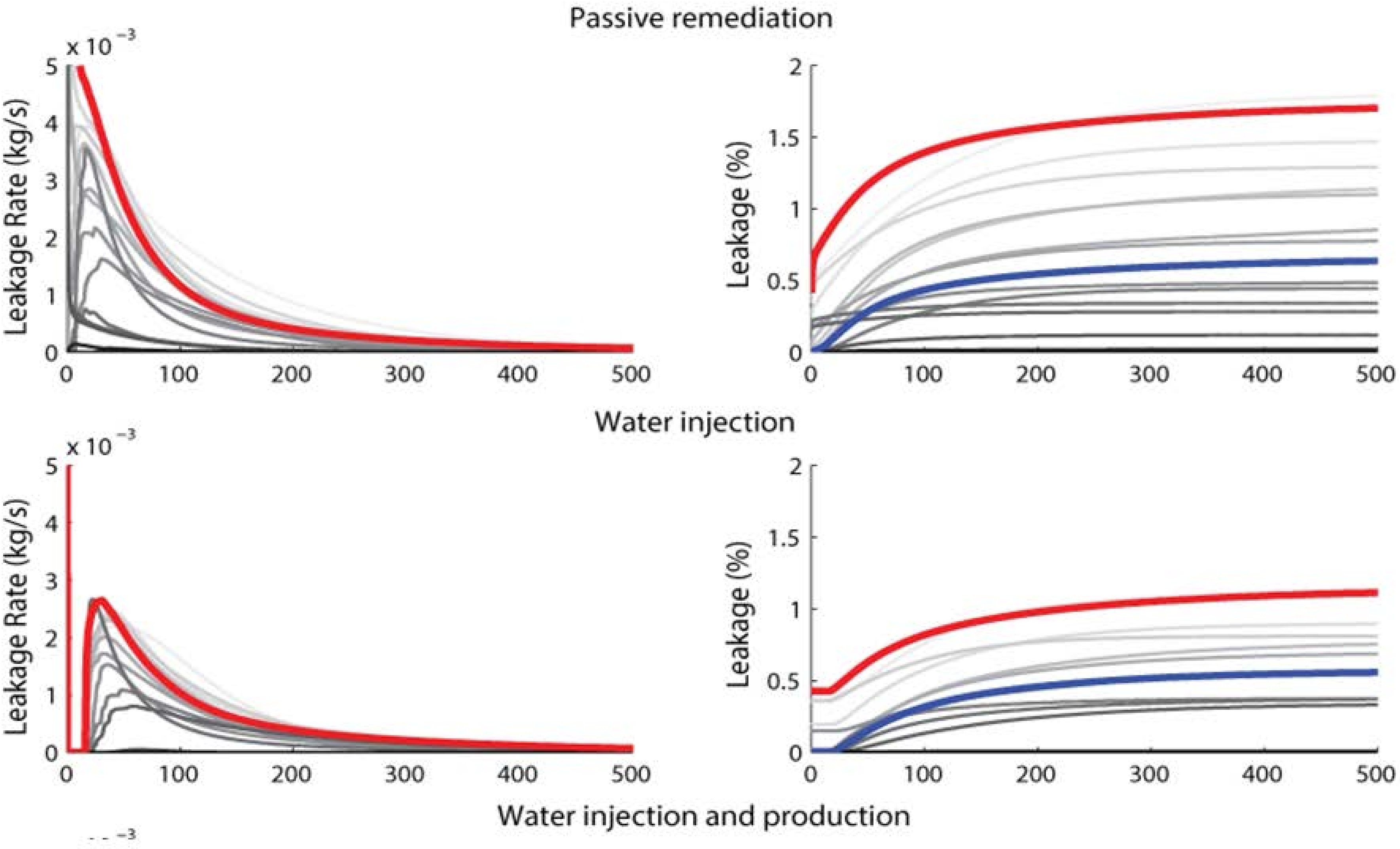
# Investigation of the Effect of Heterogeneity on Mitigation Measures





# Reservoir Heterogeneity Suppresses Leakage and Enhances Mitigation





# Conclusions



- In-zone and above-zone pressure monitoring is a powerful technique
  - Leakage detection
  - Plume Migration
- Contingency planning is needed
- Mitigation measures, particularly hydraulic controls, are effective for limiting or stopping leakage