Integration of Wellbore Pressure Measurement and Groundwater Quality Monitoring to Enhance Detectability of Brine and CO_2 Leakage

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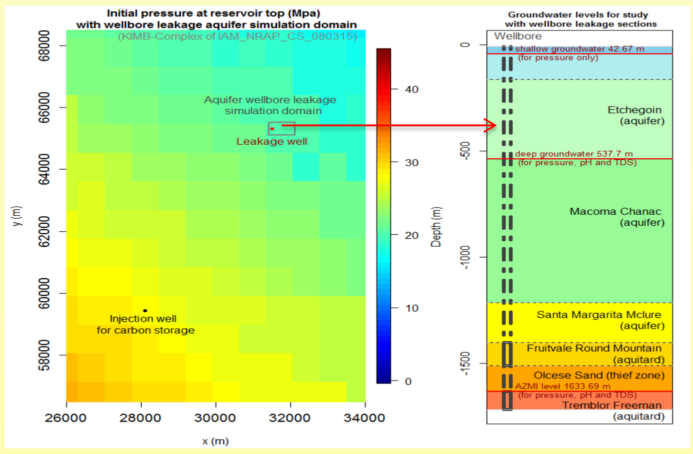
Summary

Leakage detectability is a key attribute of an effective monitoring plan. In this study, the detectability for different monitoring parameters (pH, TDS and pressure) collected from monitoring well locations were evaluated by leakage detection probability, using wellbore leakage simulations, monitoring modeling and background data at a hypothetical CO_2 storage scenario based on the Kimberlina site in south-central California. The wellbore leakage simulations at Kimberlina site are stochastic, including the variation of permeabilities in sand and clay, sodium molality, trace metal molality and organic molality and CO_2 and brine leakage rates for uncertainty quantification. Potential leakage from a wellbore into both shallow and deep groundwater layers is considered. In the example considered, leakage-induced changes were reflected in three monitoring parameters: pH, TDS and pressure at different depths, which were used to calculate the corresponding detection probabilities, based on the background distribution data and the selected monitoring technology detection thresholds. The high, median and low leakage detection probabilities of each monitoring parameter were summarized to show leakage detectability given the site uncertainty. The monitoring responses for different monitoring parameters at various depths are tested and combined to enhance the overall detectability. In particular, combing measurements, such as the ratios of formation pressure at different depths, are explored in terms of leakage detectability. The results suggest that TDS monitoring is more responsive to the simulated leakage events compared to pH monitoring, given the simulation conditions and the background data at the Kimberlina site. The direct pressure change measurement is too responsive to accurately reflect the leakage situation due to rapid propagation nature of pressure; however, combining measurements could improve the detectability. In general leakage occurring in the shallow groundwater layer is more detectable than that occurring at the deeper layer. Our analysis suggests that pressure monitoring could provide valuable indication of leakage events in early stages, while pH and TDS monitoring can tell us more detail information about the leakage response in the groundwater receptor.

Leakage Simulations and Background Distributions

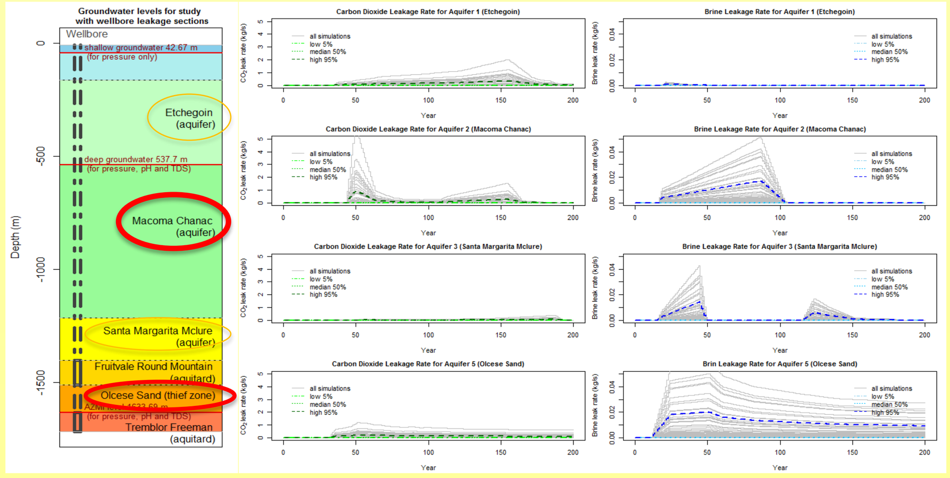
Simulation domain and the wellbore location and leakage section

The hypothetical CO_2 storage and leakage scenario is based on the Kimberlina site in south-central California. The leakage well is about 1700m deep, located about 6 km from the injection point. Three depths are selected for study: 42.67 m, 537.7 m and 1633.69 m.



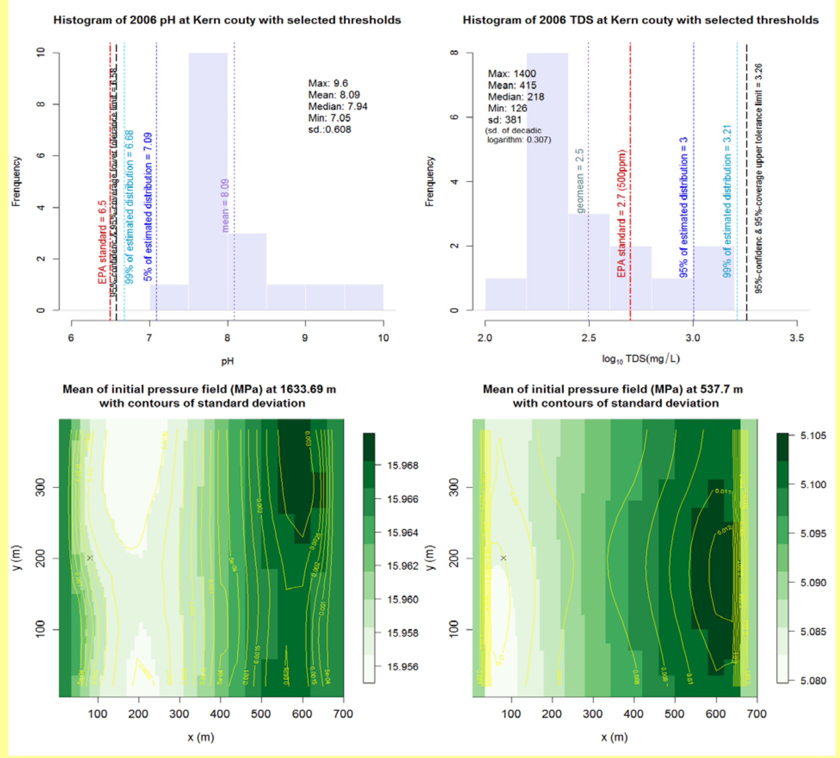
Wellbore CO_2 and brine leakage rate profiles

Four wellbore leakage sections (circled in orange and red) are considered. Macoma Chanac and Olcese Sand are the two sampling sections for monitoring TDS and pH. We used 200 realizations to quantify the leakage impact uncertainty. The corresponding CO_2 and brine leak rates for each leakage sections are also shown.



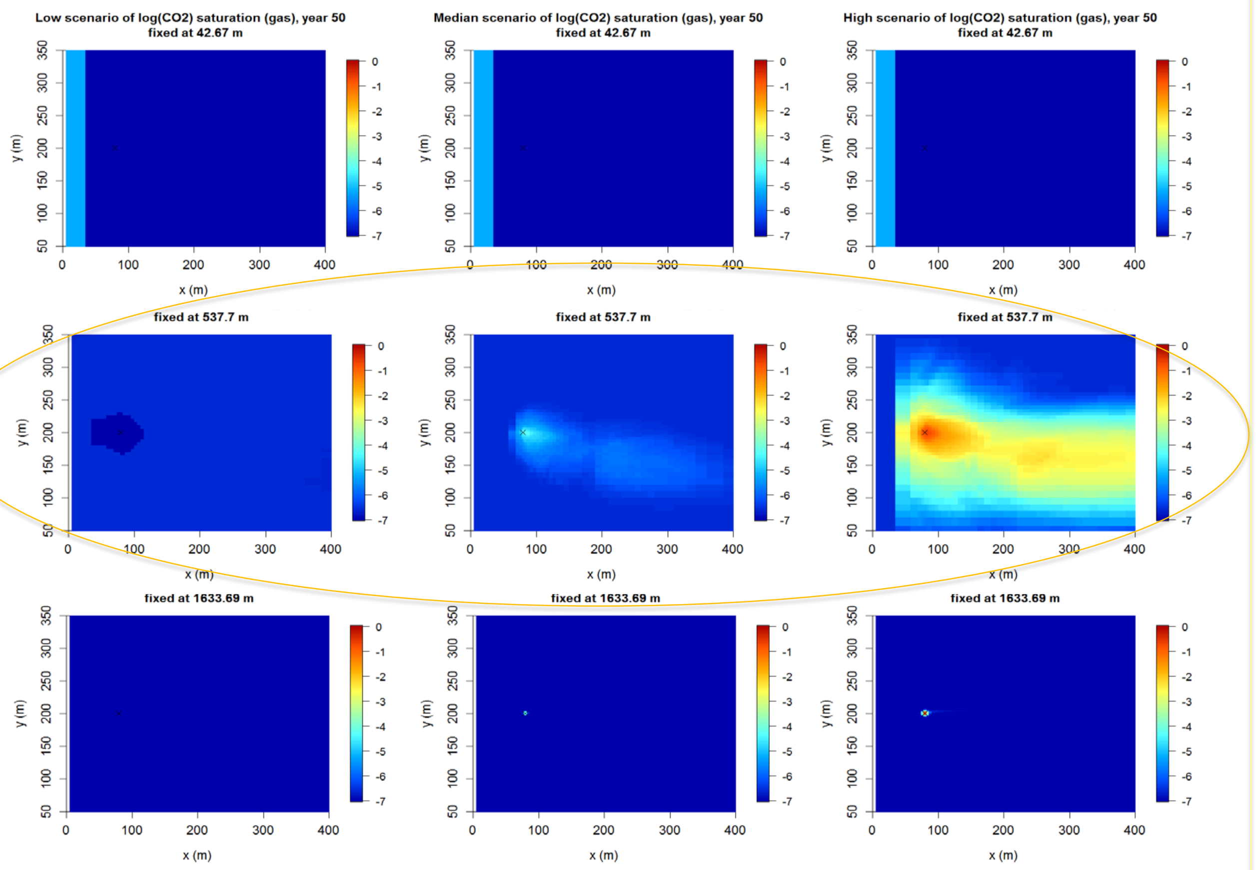
Background distributions of pH, TDS and Pressure

Background distributions of pH, TDS come from Kern County groundwater quality data, 2006. Conventional lab analysis methods (residue TDS and water sample pH) are assumed based on the data report. Background pressure data are from the initial simulation data with variance contributed from geologic parameter uncertainty (permeability, porosity, etc.). Normal distributions are assumed for all three monitoring parameters after distribution goodness of fit tests.

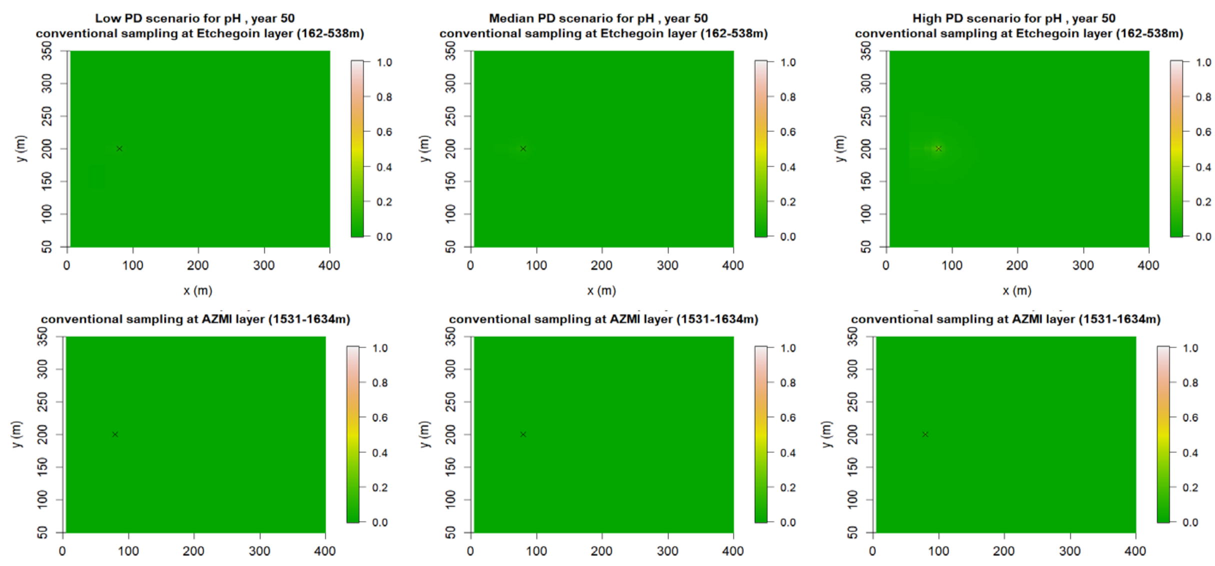


PH and TDS Probability of Detection (PD) using no-impact threshold given Low, Median and High Scenarios

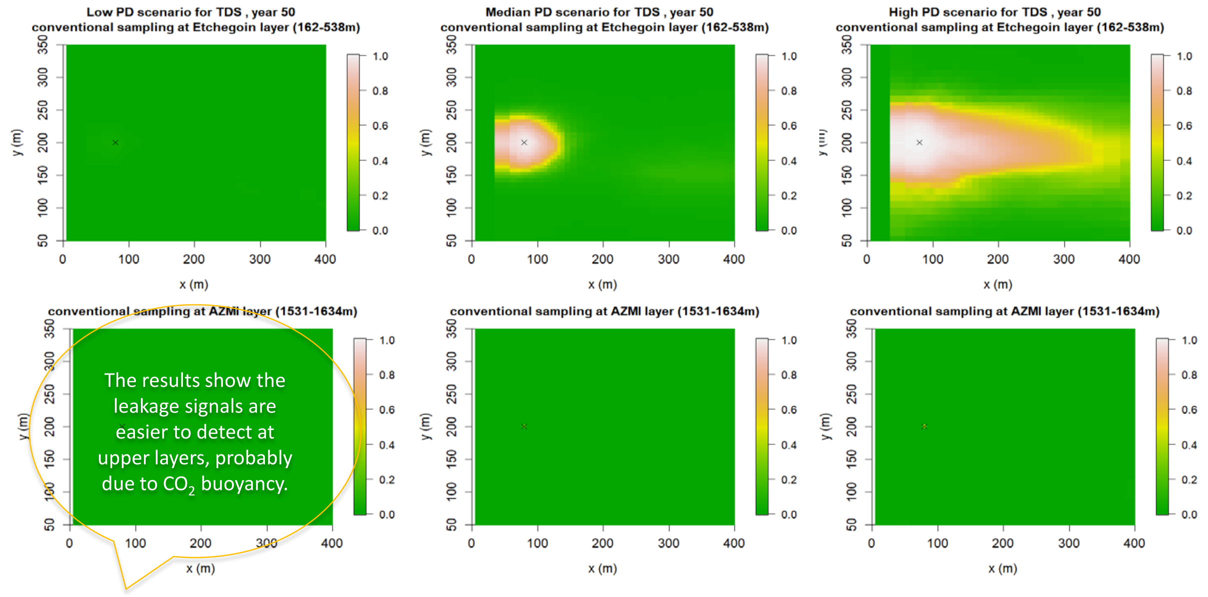
Original simulated $CO_{2(gas)}$ saturation at various depths



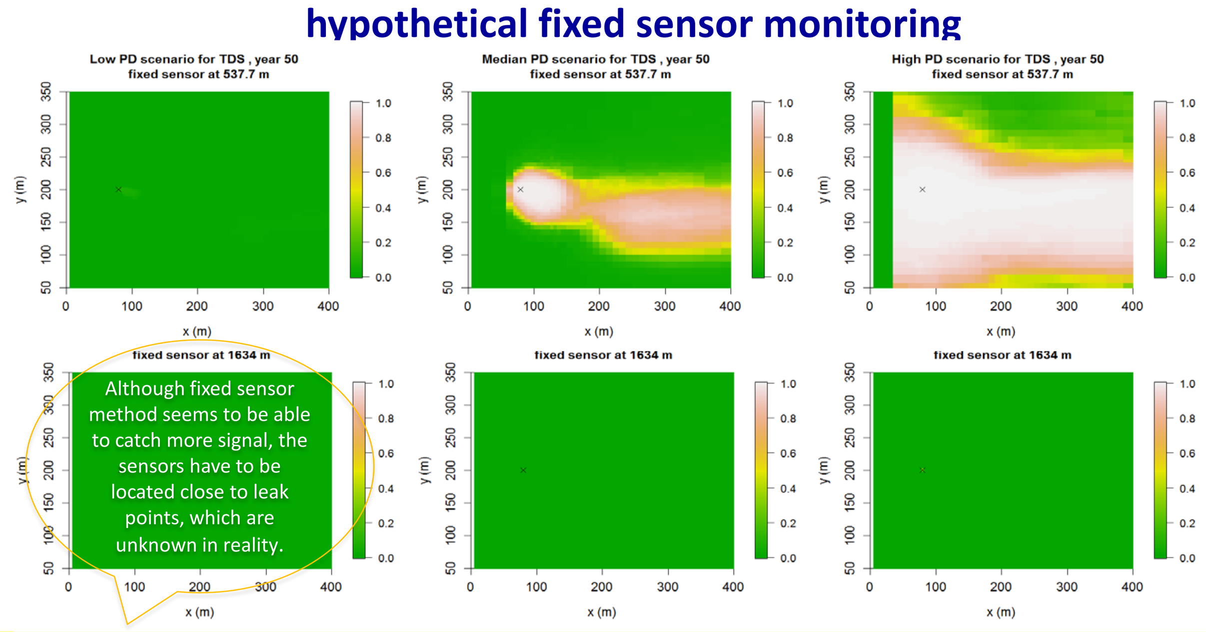
pH PDs at two depths using no-impact threshold and conventional groundwater monitoring (baseline method)



TDS PDs at two depths using no-impact threshold and conventional groundwater monitoring (baseline method)

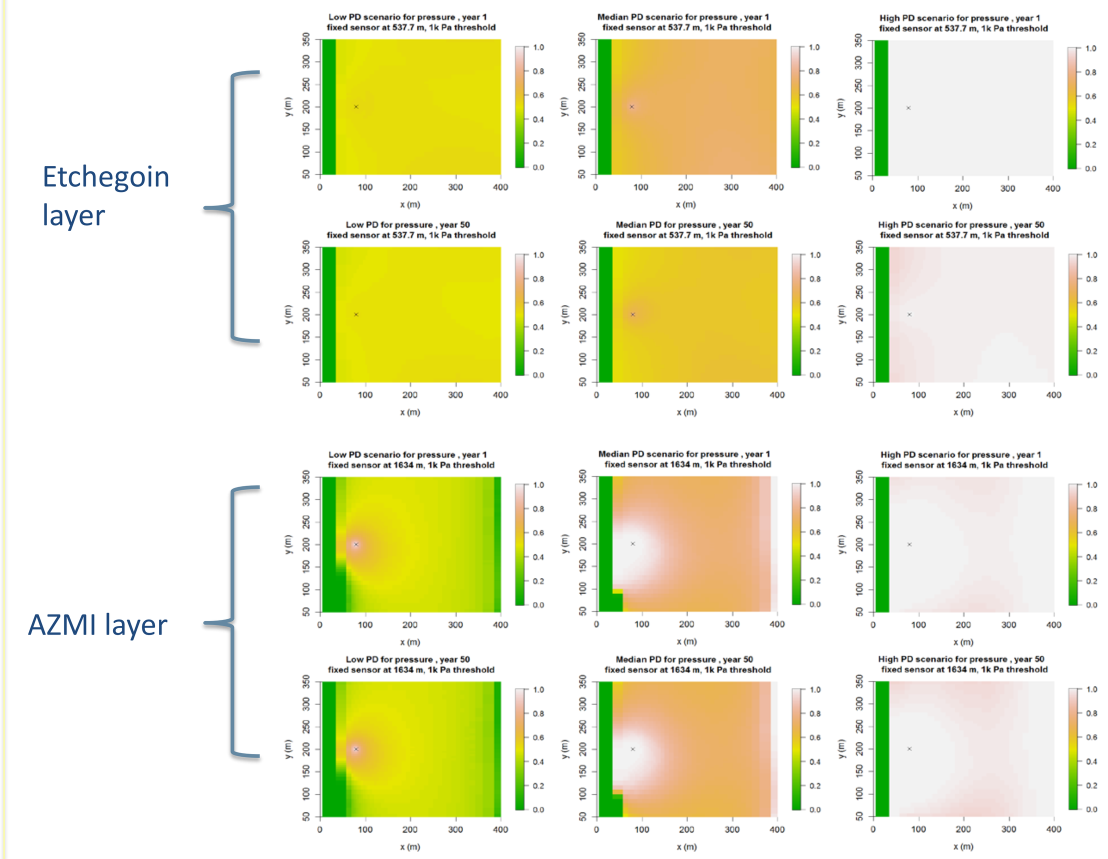


TDS PDs at two depths using no-impact threshold and hypothetical fixed sensor monitoring

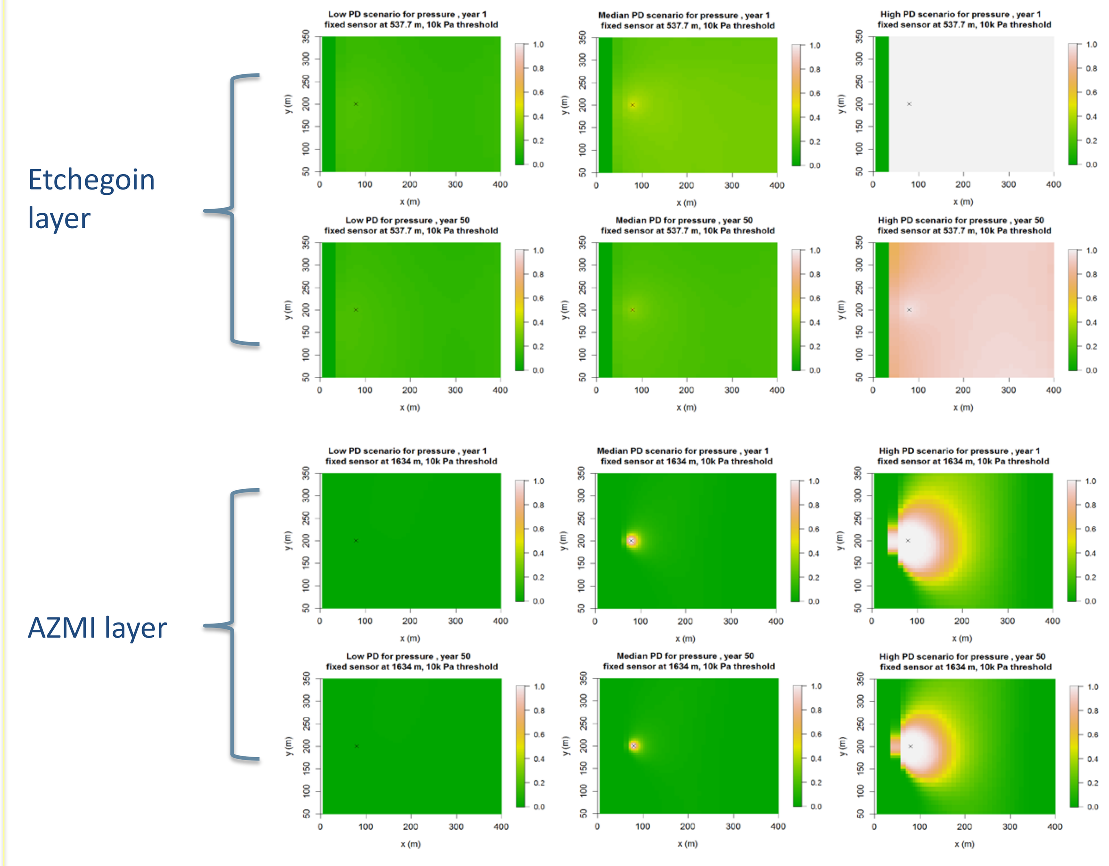


Pressure PDs using Different Thresholds given Low, Median and High Scenarios

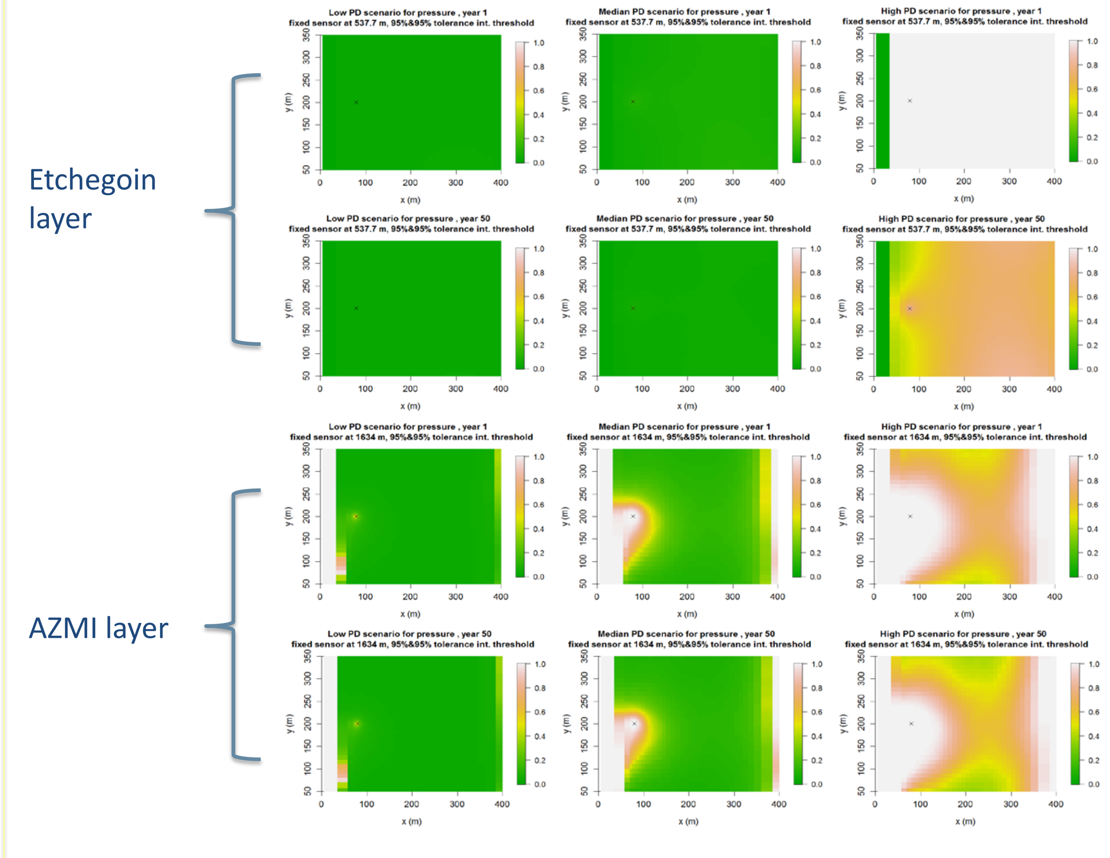
Pressure PDs at two depths using 1k Pa change threshold and fixed sensor monitoring



Pressure PDs at two depths using 10k Pa change threshold and fixed sensor monitoring

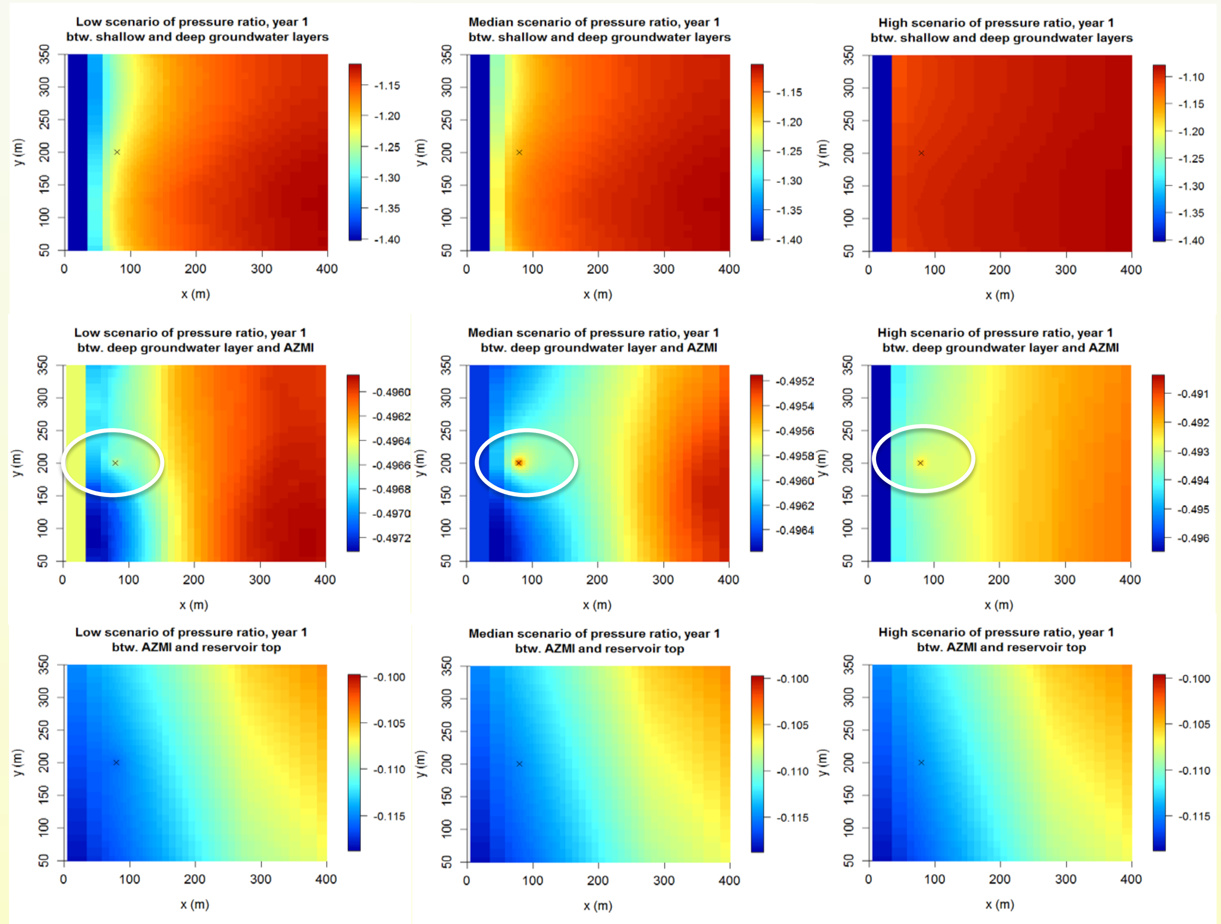


Pressure PDs at two depths using 2D no-impact thresholds and fixed sensor monitoring

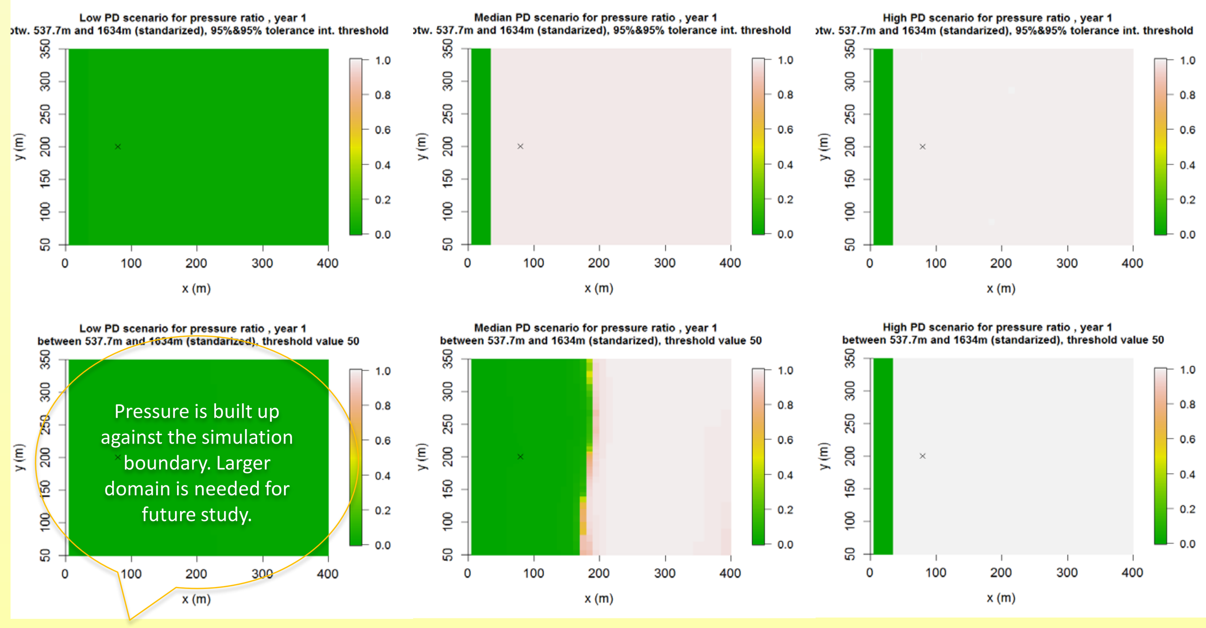


Some Test Results about Pressure Ratios at Different Depths

Ratios Between aquifers and the reservoir top



Pressure ratio PDs using ratio distribution



Conclusion :

- The results suggest that TDS monitoring is more responsive to the simulated leakage events compared to pH monitoring, given the simulation conditions and the background data at the Kimberlina site. However, they are not as responsive as pressure measurement.
- Pressure measure could provide early indication of leakage events, but inference of leakage location would require additional information.
- Pressure measurement at various depths with appropriate detection threshold seems better for anomaly detection and is useful for monitoring upward migration of leaked fluids. The pressure ratios (Azzolina et al., 2014) tested in our study show too much sensitivity, and the boundary condition issue is thus amplified.

Future Work :

- **Update the PD estimations with updated and coupled wellbore leakage simulation scenarios and Kimberlina reservoir injection simulation results.**
- **Test the application of selecting pressure detection thresholds and multi-layer monitoring information using inverse modeling.**
- **Continue exploring detectability with various combined measures.**

ACKNOWLEDGEMENTS

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