ARB Contract Interim: Important Site Selection Traits (With Quantification and Monitoring Implications)

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Curt Oldenburg

ARB GCS Site Selection Technical Discussion

20160926

Energy Geosciences
EARTH & ENVIRONMENTAL SCIENCES AREA

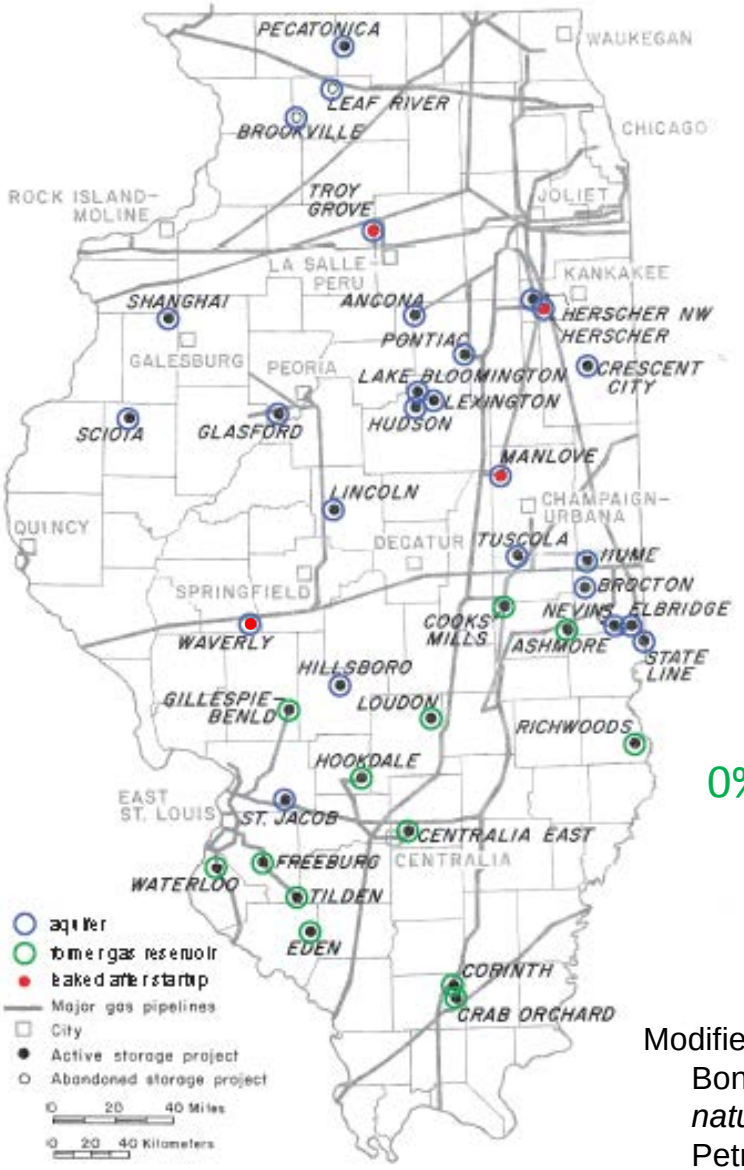
BERKELEY LAB
Lawrence Berkeley National Laboratory

Criteria List for Review From ARB

- historical use considerations (oil and gas production, hydraulic fracturing, abandoned wells, etc.);
- minimum injection depth;
- minimum cap-rock thickness;
- delineation of an area of review;
- minimum pore-space capacity in relation to estimated injection volumes;
- identification of potential leakage pathways for CO_2;
- proximity to emission sources and potential of source for CO_2 capture
- proximity to population centers;
- seismic hazard considerations;
- establishing pipeline or other transportation rights-of-way;
- setting requirements for baseline data collection, including levels and other sources of CO_2 emissions, groundwater chemistry, and micro-seismicity; and
- necessary geologic models and CO_2 flow simulations

Historical Use

Natural gas storage in Illinois as of 1973



~25% of saline leak

~10% upon testing

~15% early in operation (mitigation allows continued operation: 1 backup interval, 3 active management)

"Finding suitable storage in aquifers is difficult, and the ultimate testing of aquifers can be done only by injecting gas. Therefore, we can expect to encounter, from time to time, a structure that appears to be worthy of testing but later proves unsatisfactory for gas storage."

0% of depleted fields leak

Modified from Buschback, T.C., and D.C. Bond (1973). *Underground storage of natural gas in Illinois – 1973*, Illinois Petroleum 101, Illinois Geological Survey, Urbana, Illinois, 71 pp.

Historical Use: None (Saline)

Statoil exploration results as of 1996

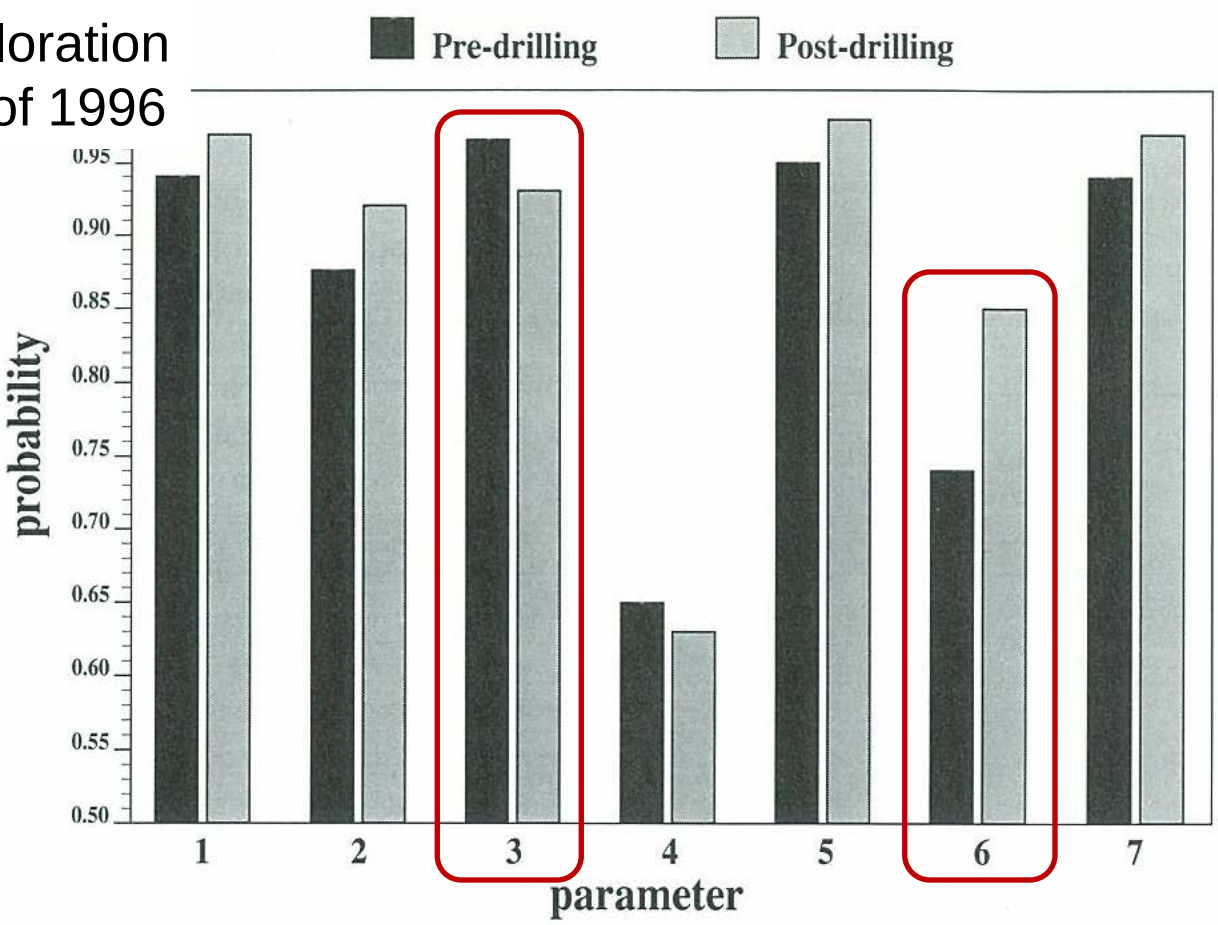


Fig. 1. Pre- and post-drilling assessments of risk parameters for prospects on the Norwegian continental shelf. *1* =closure; *2* =reservoir rock existence; *3* =porosity; *4* =source, maturation and migration; *5* =timing; *6* =trapping/leakage; *7* =recovery. See text for further explanations.

Hermanrud, C., K. Abramsen, J. Vollset, S. Nordahl, and C. Jourdan (1996). Evaluation of undrilled prospects – sensitivity to economic and geologic factors. In: A.G. Dore and R. Sinding-Larsen (editors), *Quantification and Prediction of Hydrocarbon Resources, Proceedings of the Norwegian Petroleum Society Conference, 6-8 December 1993, Stavanger, Norway*. Norwegian Petroleum Society (NPF) Special Publication No. 6, Elsevier, Amsterdam, pp. 325-337.

Historical Use: None (Saline)

Saline aquifer carbon storage as of now

Project	Location	Start	Capacity (Mtpa)
Sleipner	Norway	1996	0.9
In Salah	Algeria	2004	0.0 (injection suspended)
Snøhvit	Norway	2008	0.7
Quest	Canada	2015	1.0

Insufficient injectivity

Global CCS Institute (2016). Large scale storage projects. http://www.globalccsinstitute.com/projects/large-scale-ccs-projects accessed on 20160923

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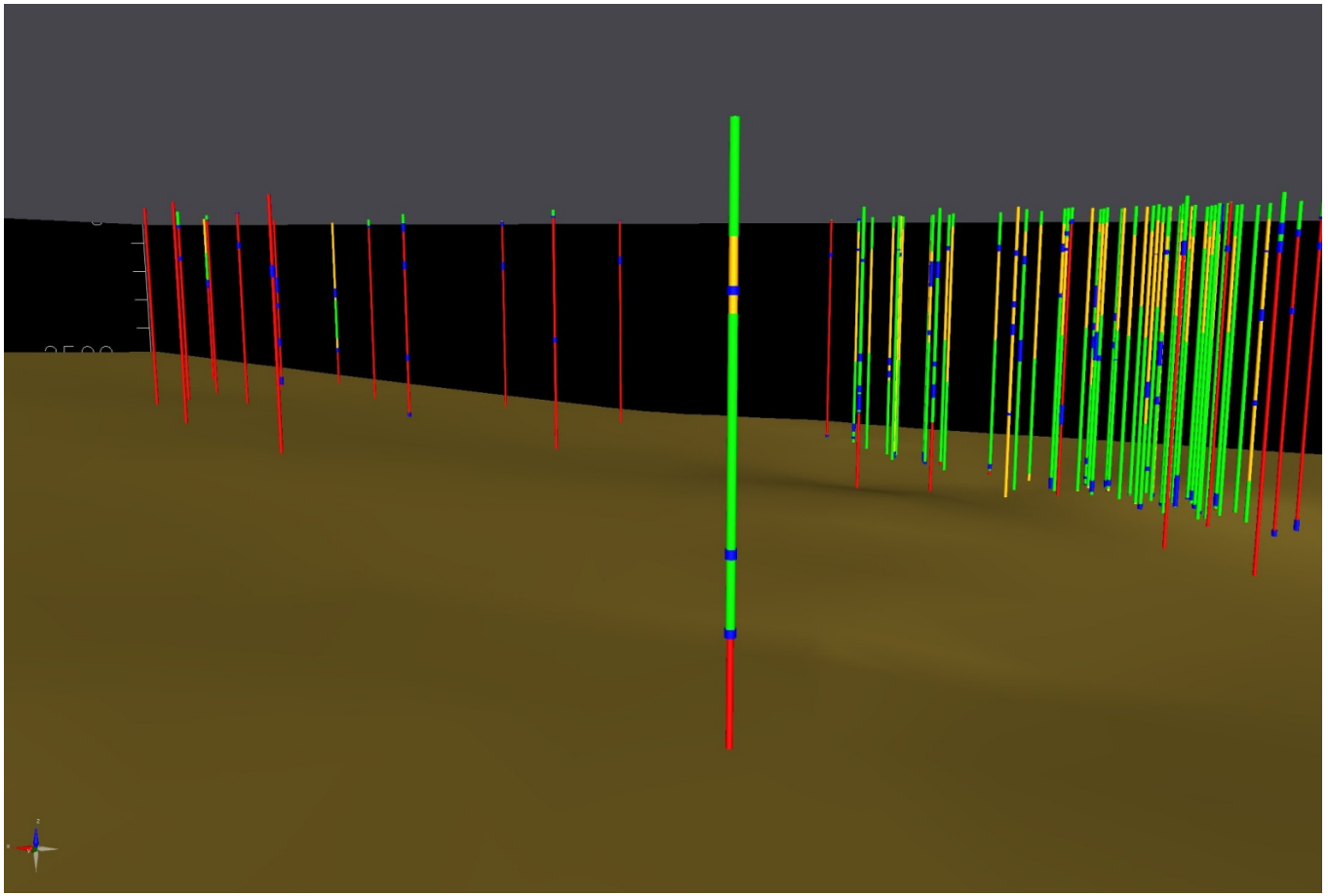
Backup zone

Global CCS Institute (2016). Large scale storage projects. http://www.globalccsinstitute.com/projects/large-scale-ccs-projects accessed on 20160923

Historical Use: Oil and Gas Production

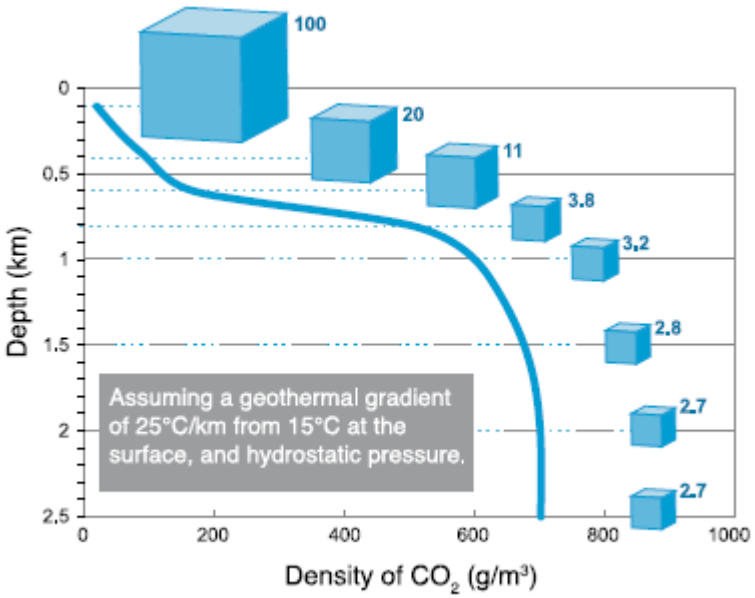


Blue segments are plugs

Red segments are unsealed borings

Jordan, P. D., and J. Wagoner (2016). *Kimberlina Site: Existing Wells to the Storage Target;*; NRAP-TRS-III-XXX-2016; NRAP Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Morgantown, WV, 2016; *In Press*.

Minimum Injection Depth



Benson, S. M., and P. Cook (coordinating authors, 2005). Underground geological storage. *In*: Intergovernmental Panel on Climate Change Special Report on Carbon Dioxide Capture and Storage, P. Freund (coordinating author). Cambridge University Press, Cambridge, U.K., pp. 195-276.

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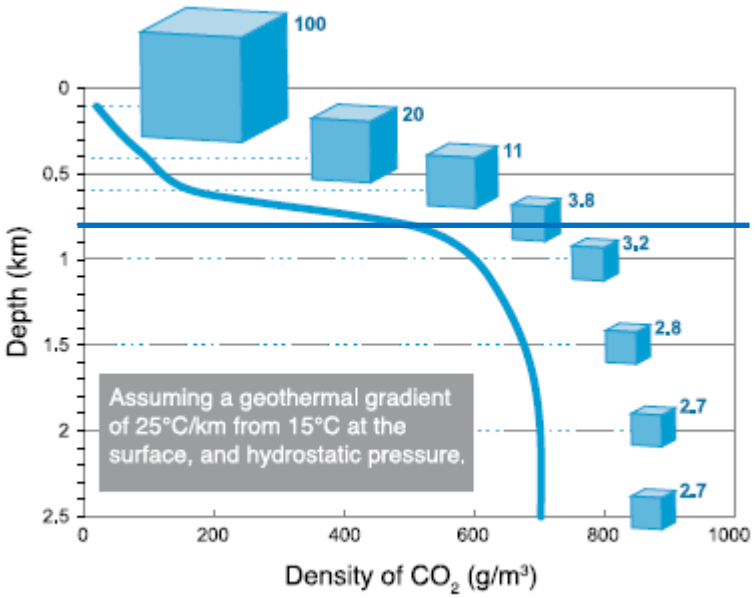
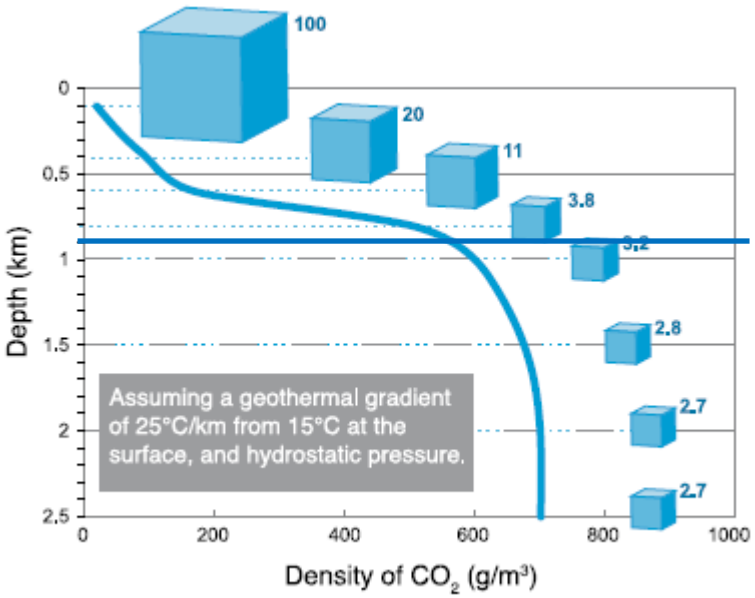


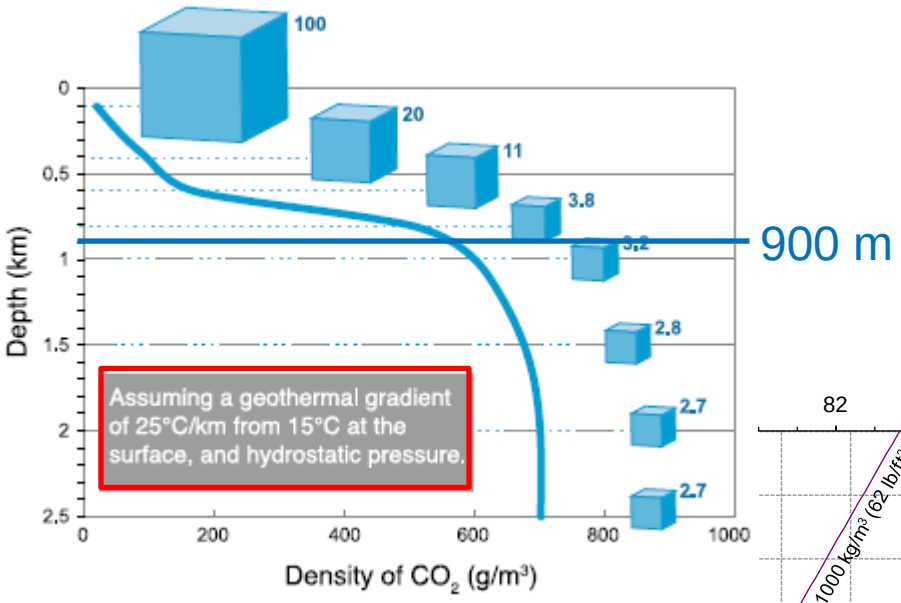
800 m

Minimum Injection Depth



900 m

Minimum Injection Depth



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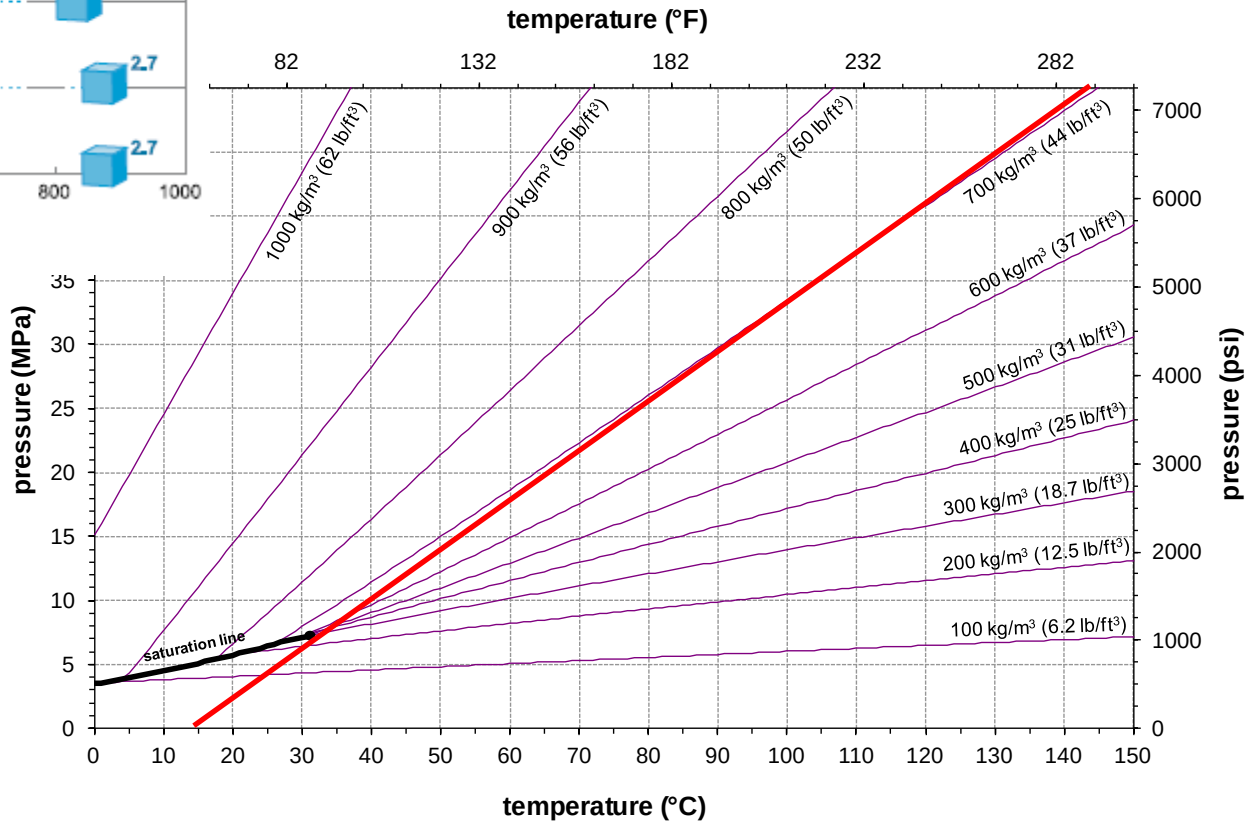

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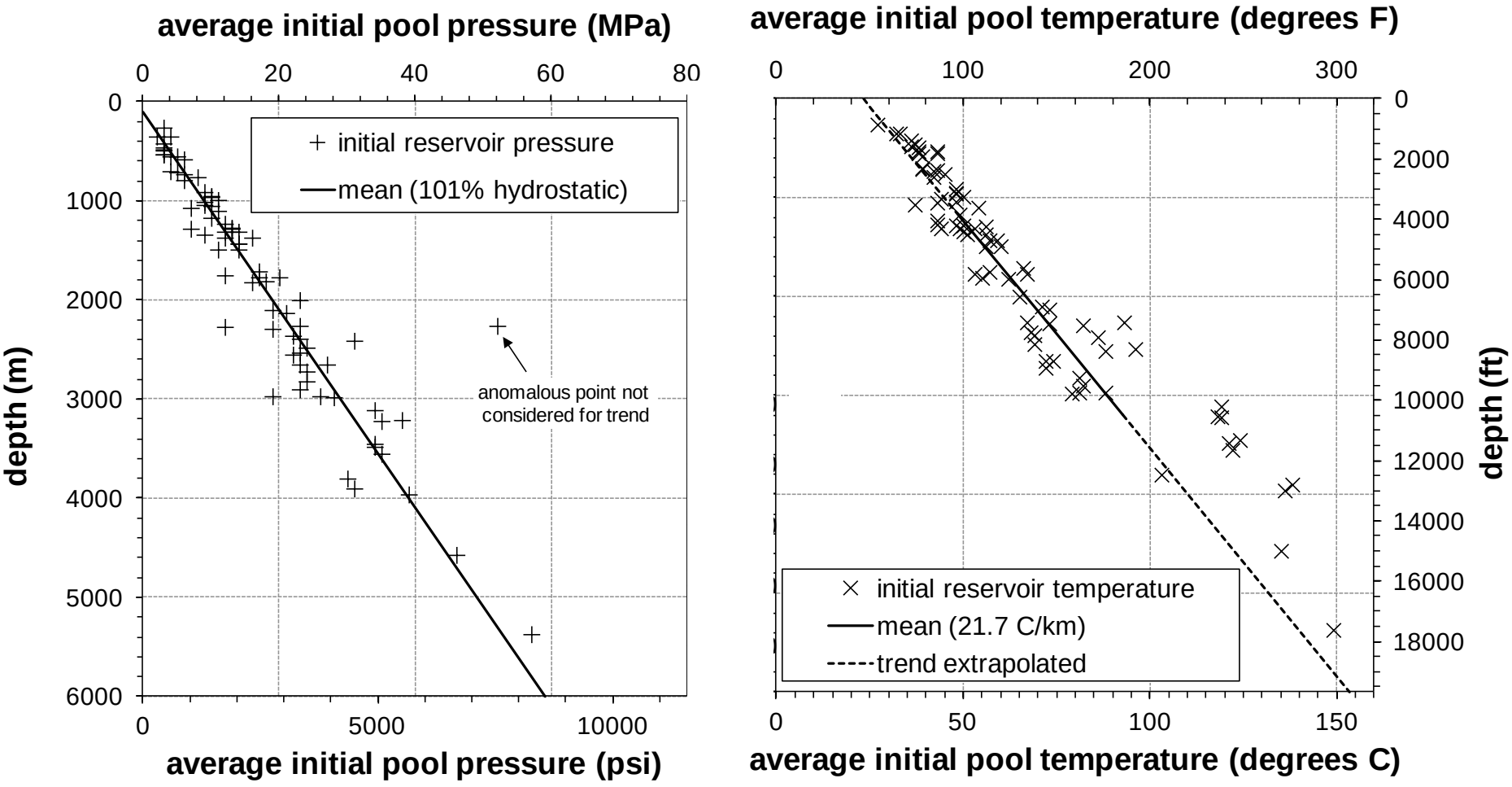

Jordan, P.D., and Doughty, C. (2009). Sensitivity of CO_2 migration estimation on reservoir temperature and pressure uncertainty. *In*: Gale, J., Herzog, H., and Braitsch, J. (eds), *Greenhouse Gas Control Technologies 9, Proceedings of the 9th International Conference on Greenhouse Gas Control Technologies (GHGT-9), 16–20 November 2008, Washington DC, US*, Energy Procedia, February 2009, 1: 2587-2594.

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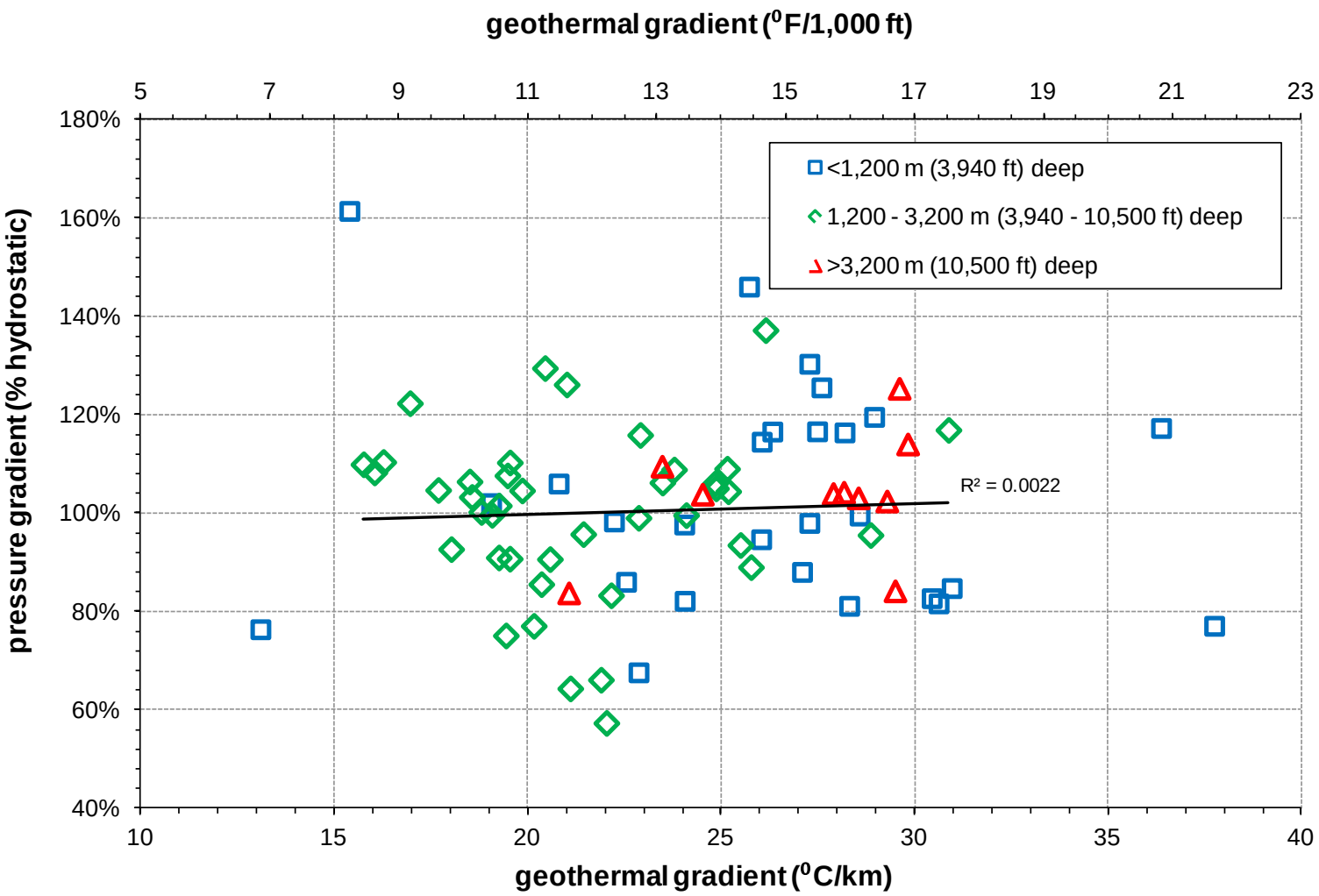

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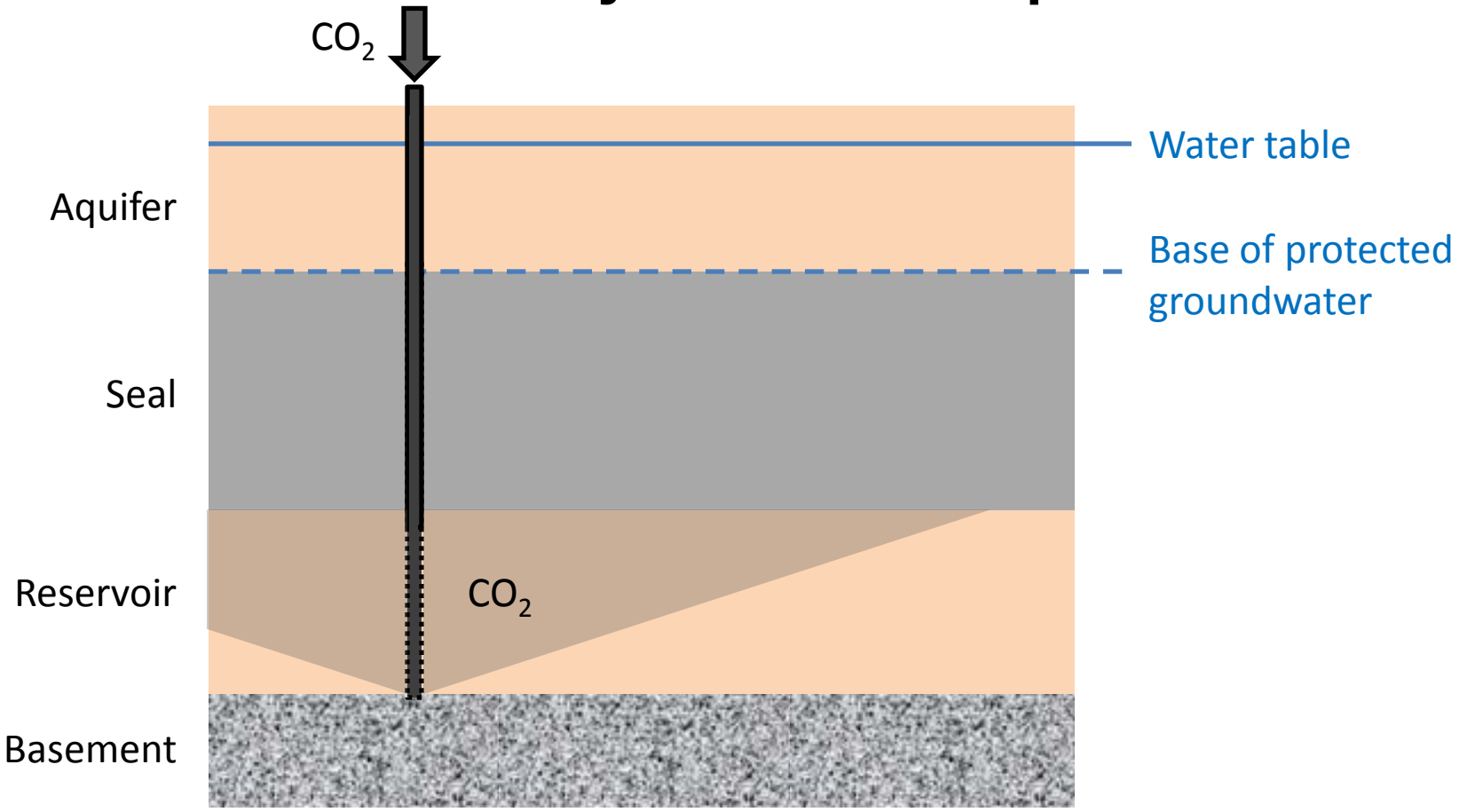

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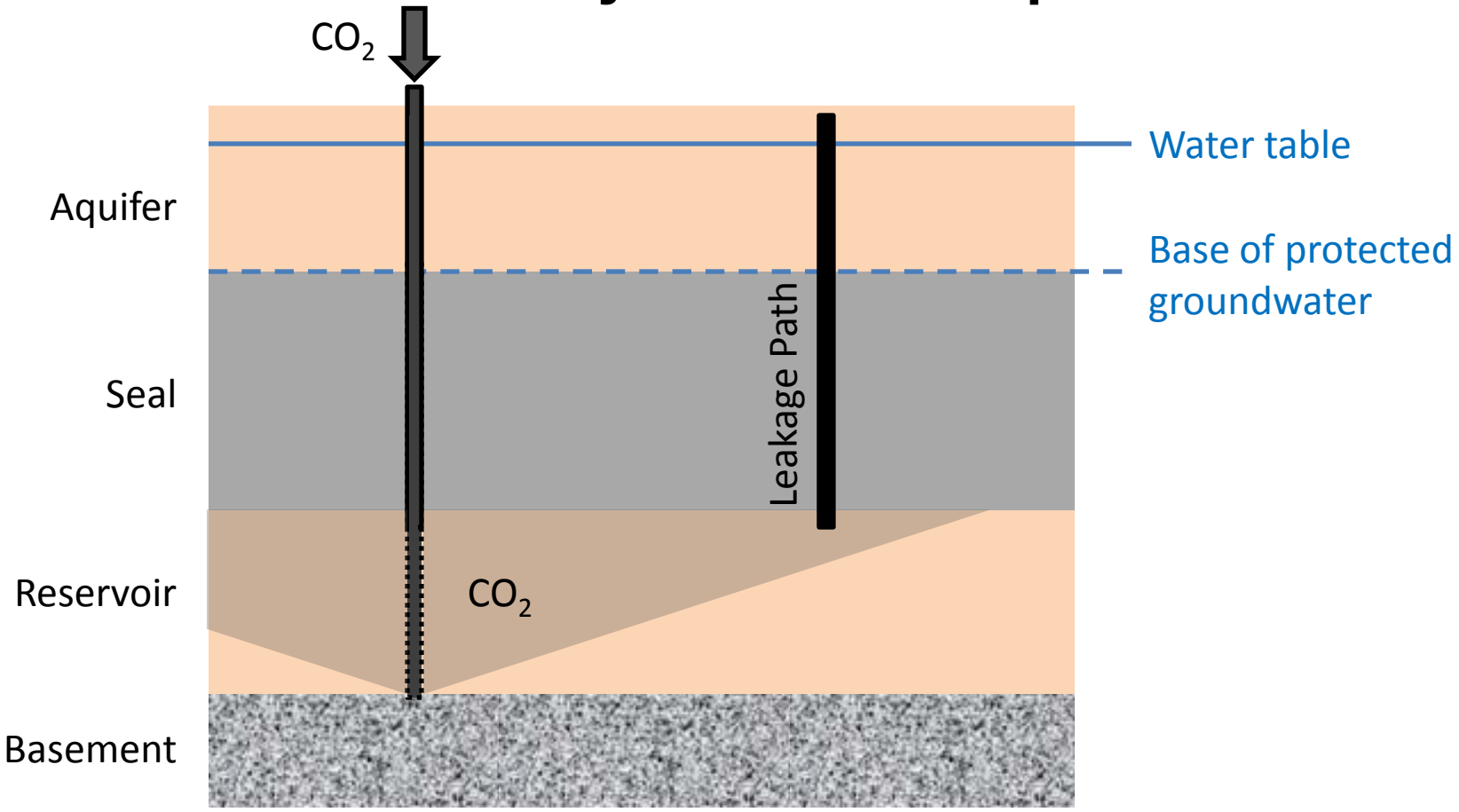

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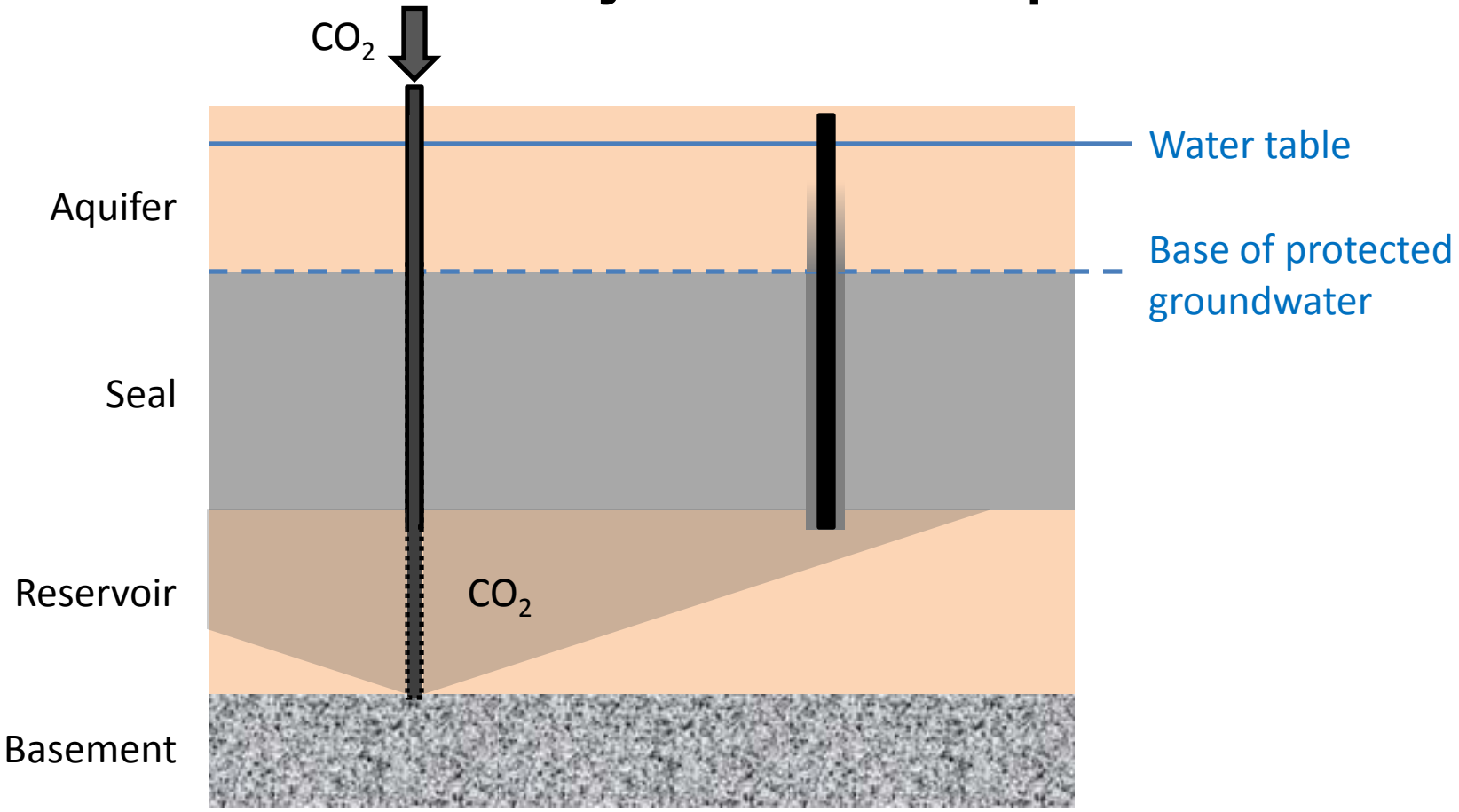

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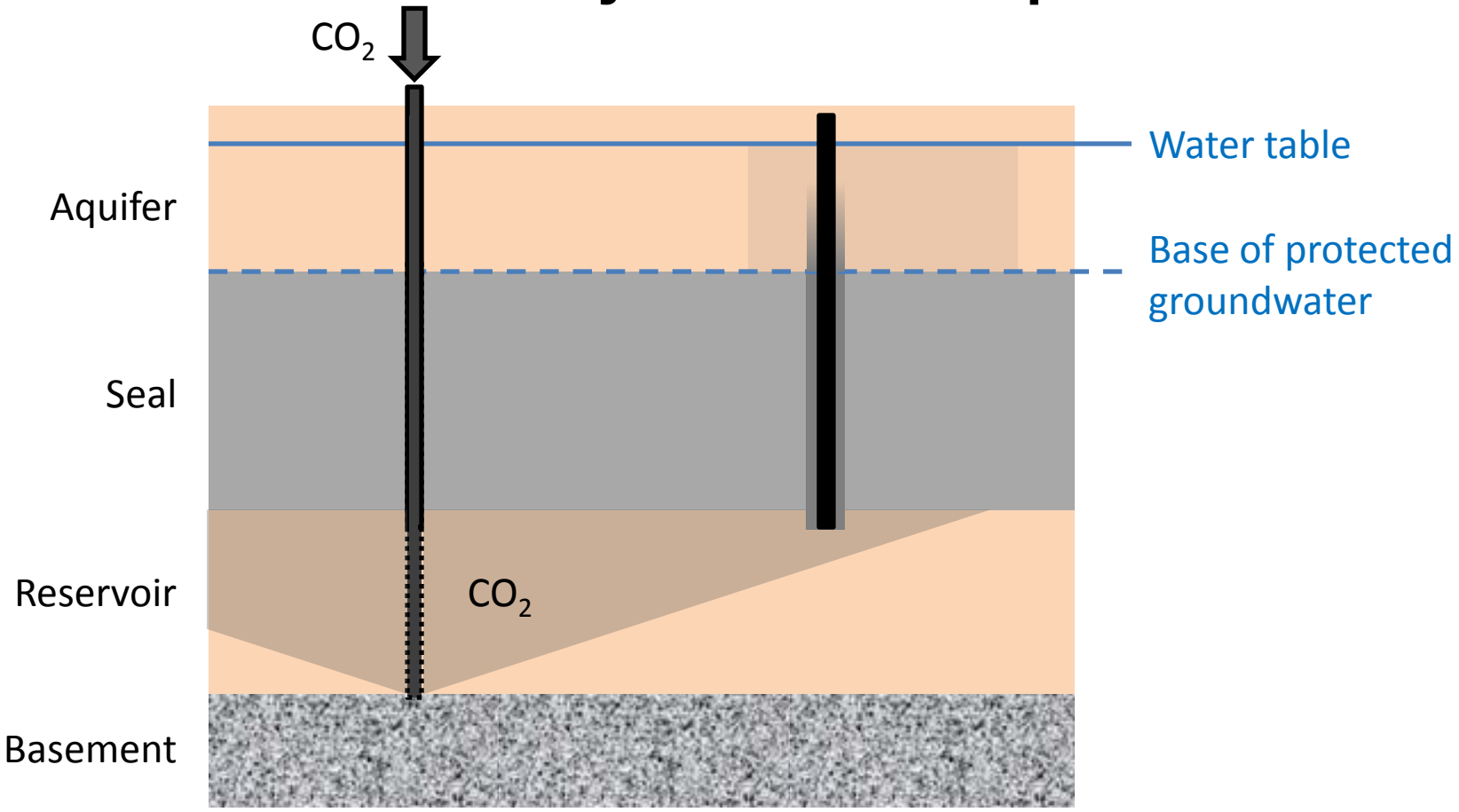

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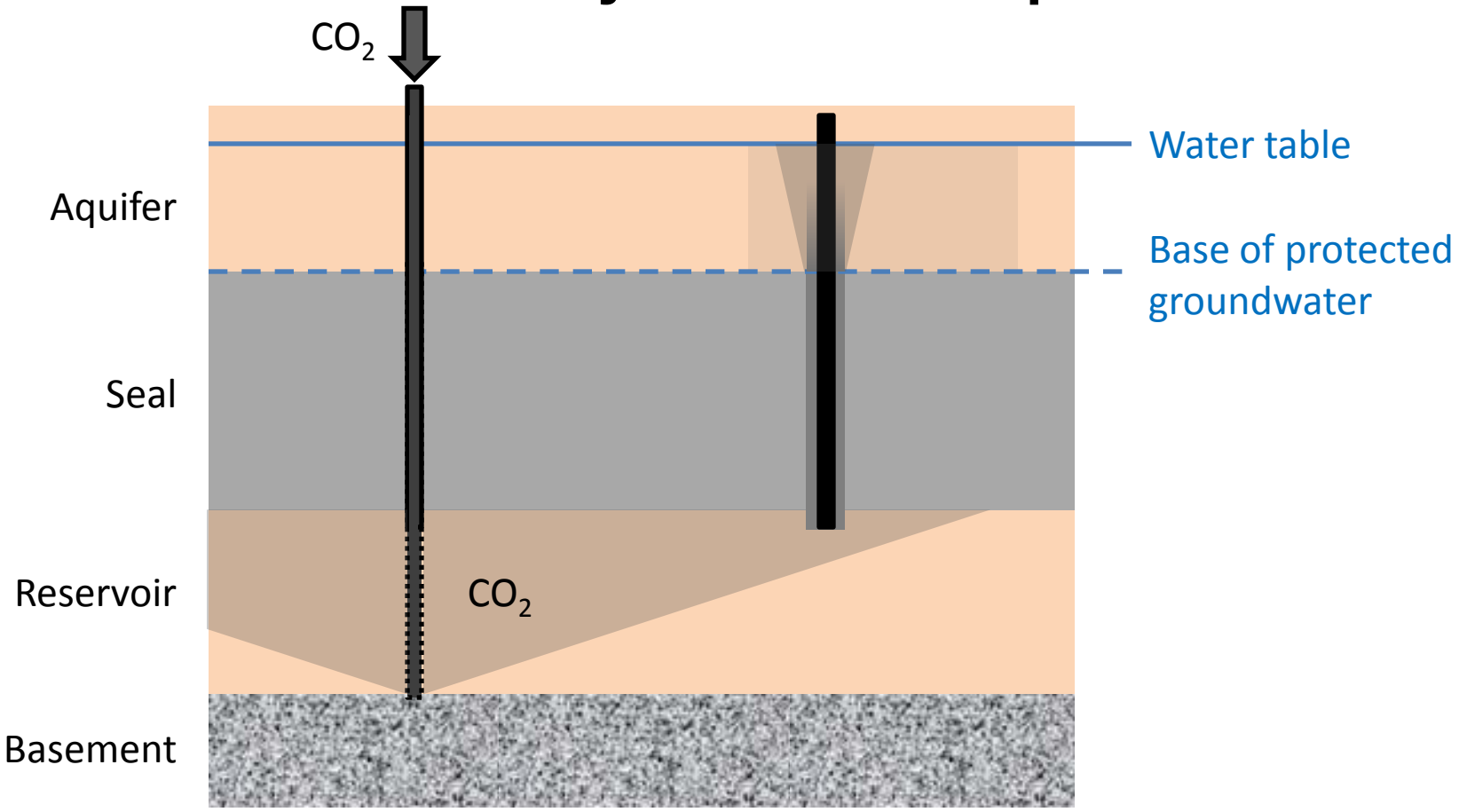

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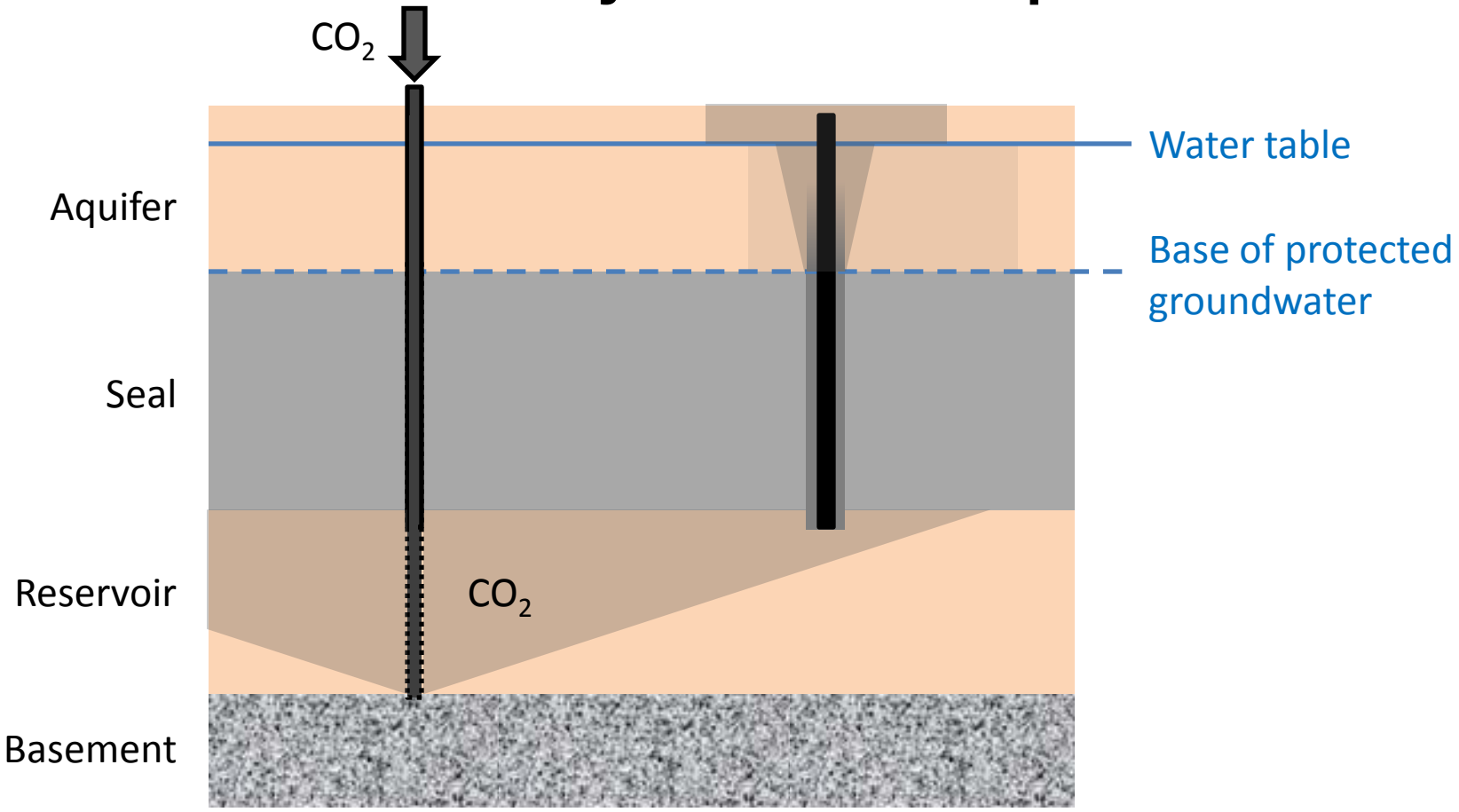

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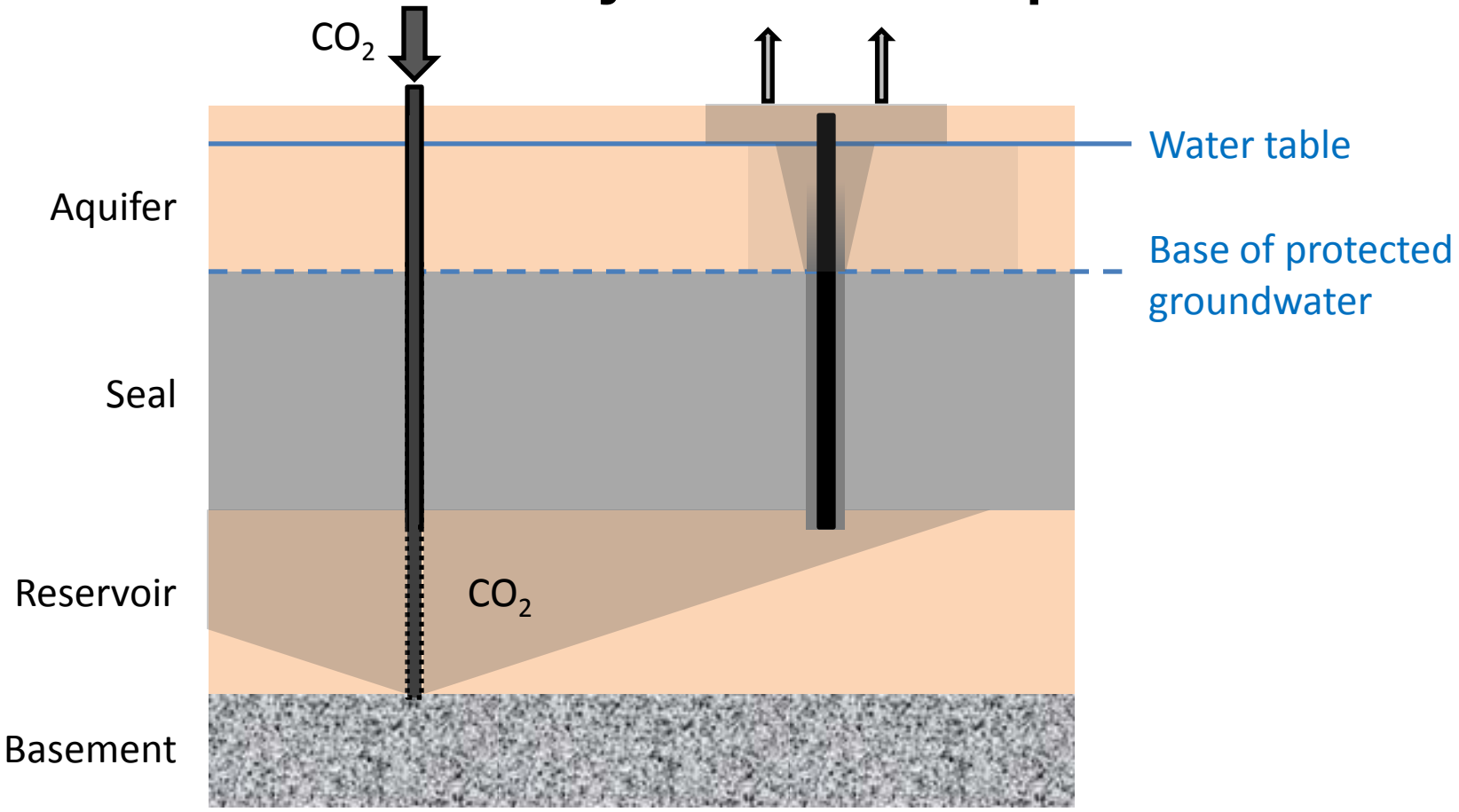

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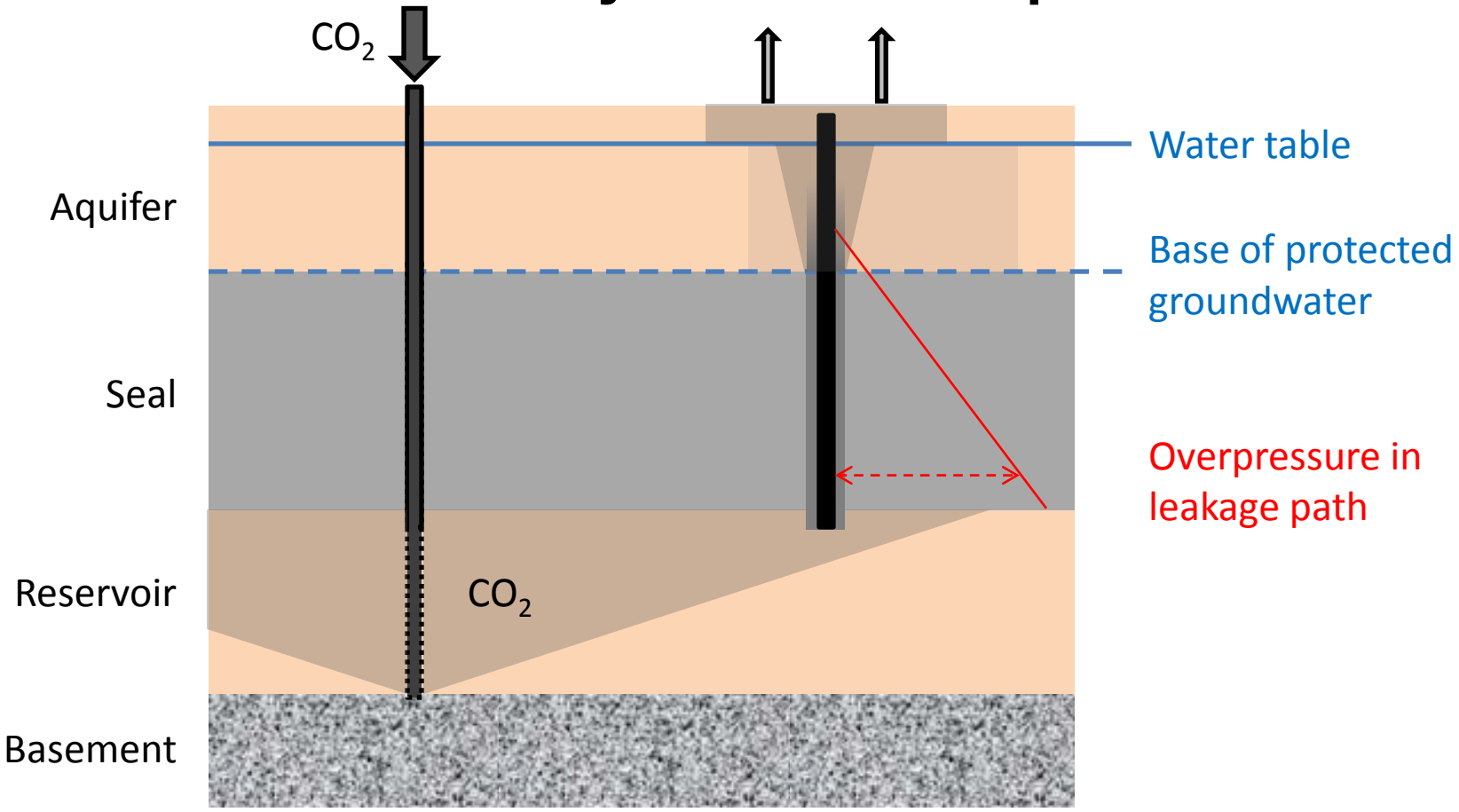

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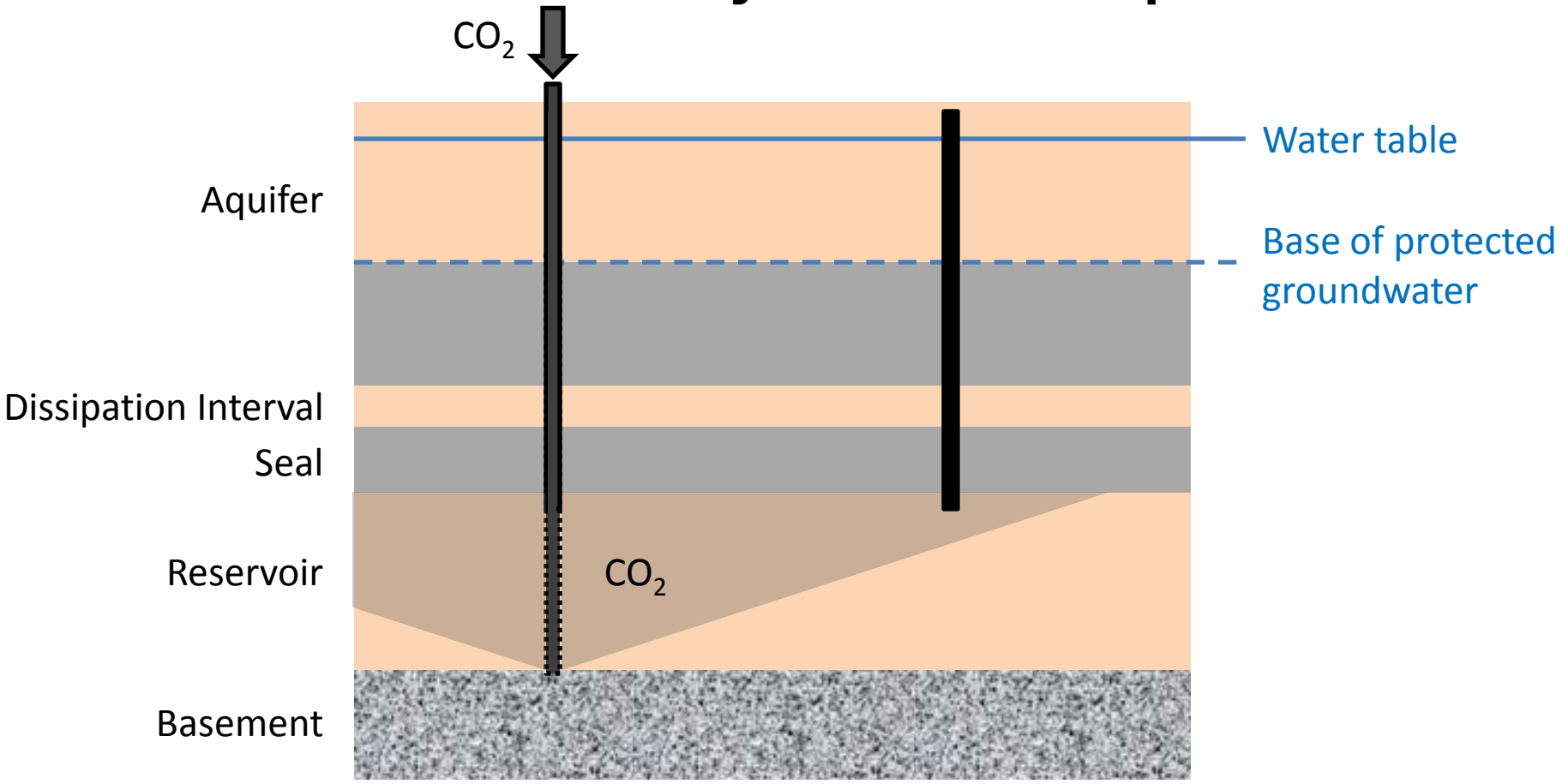

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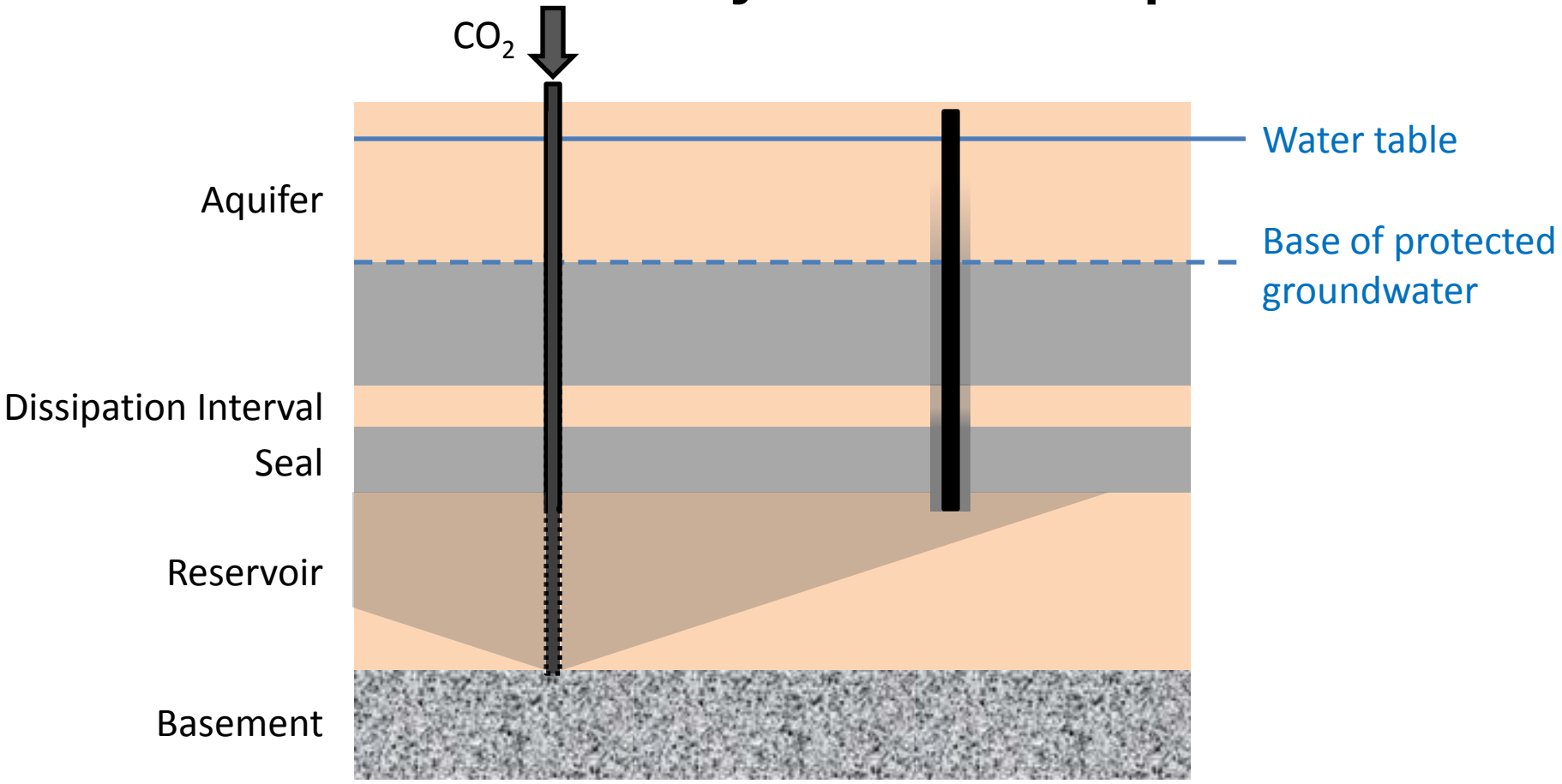

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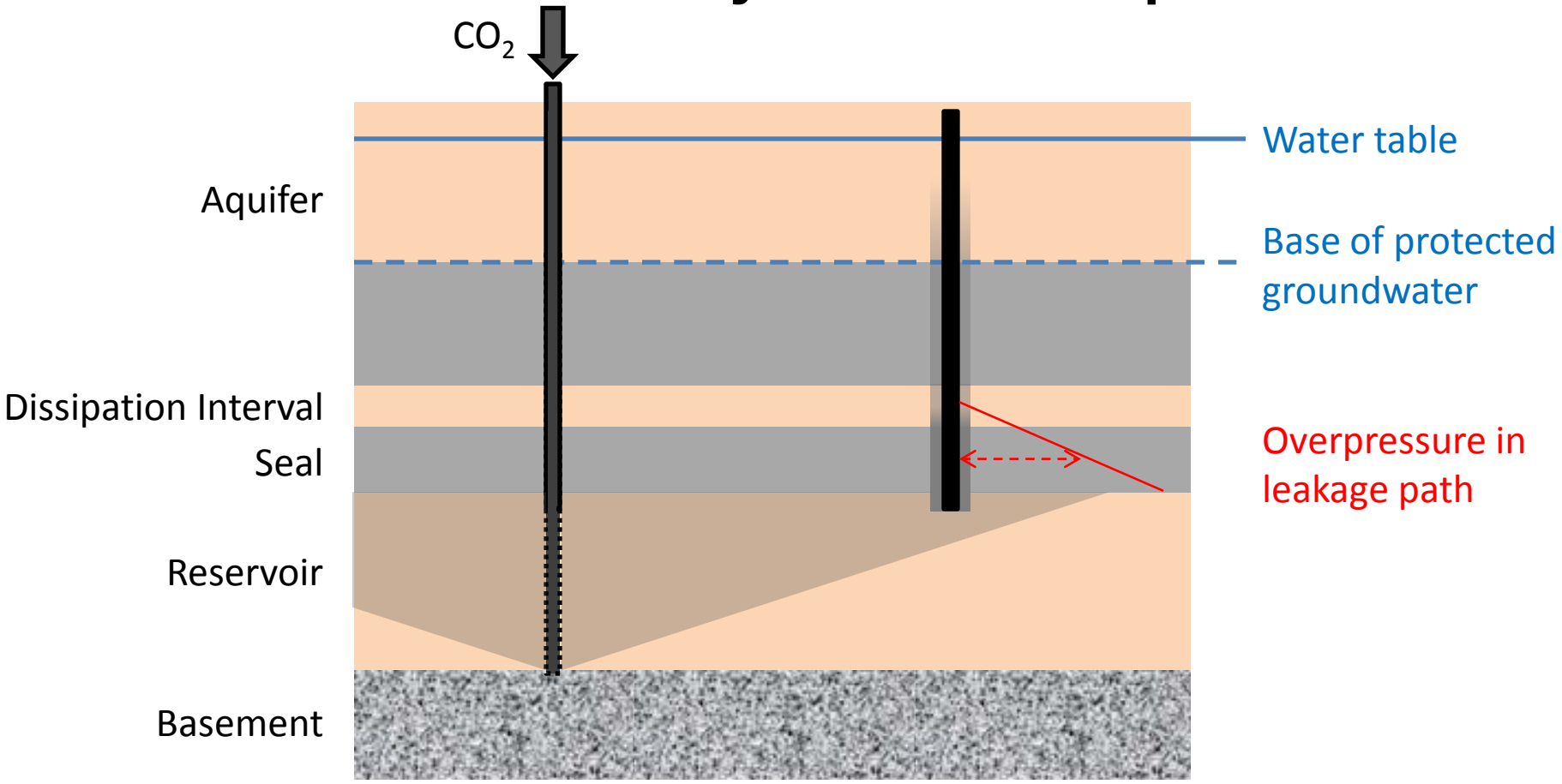

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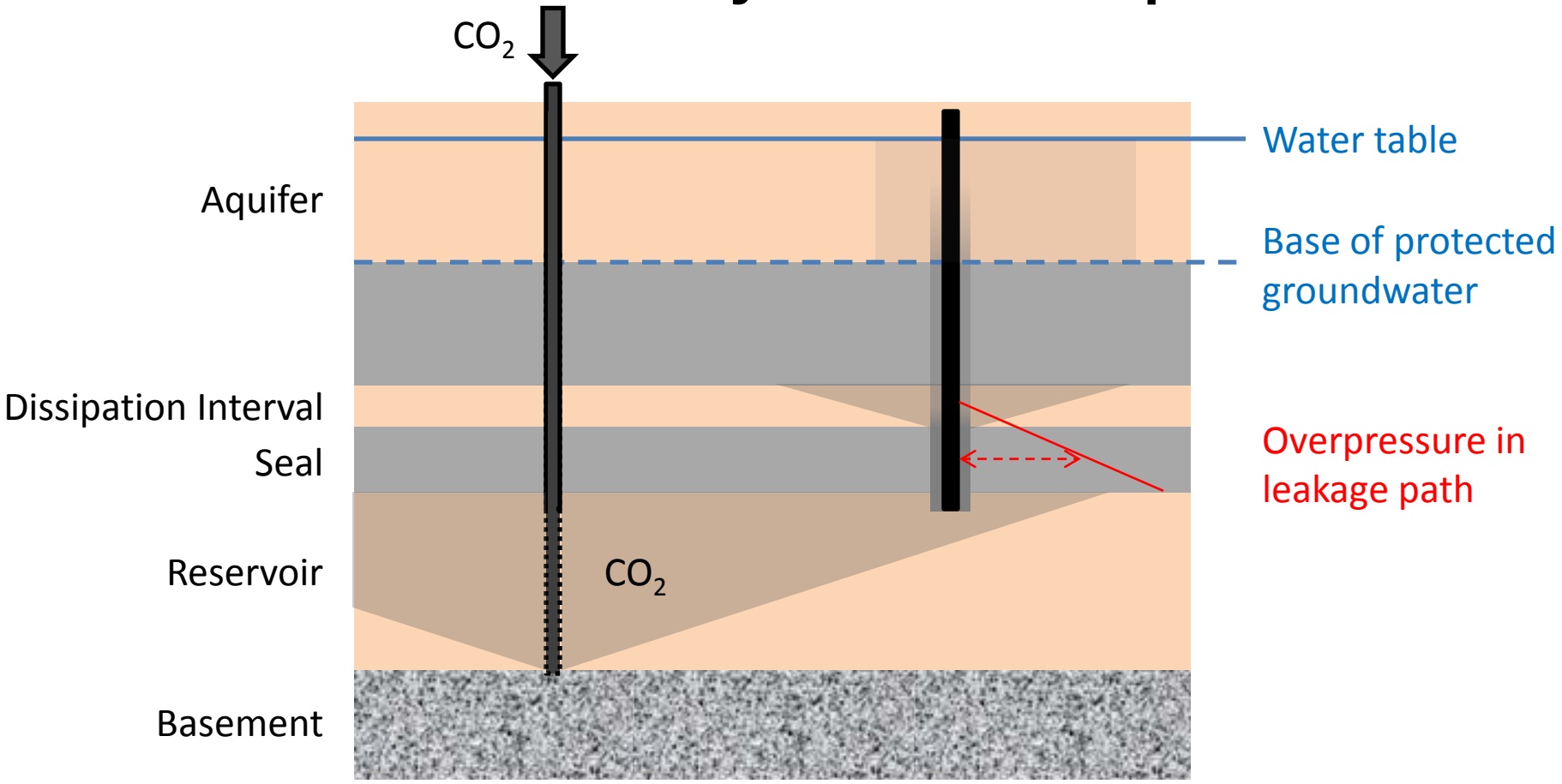
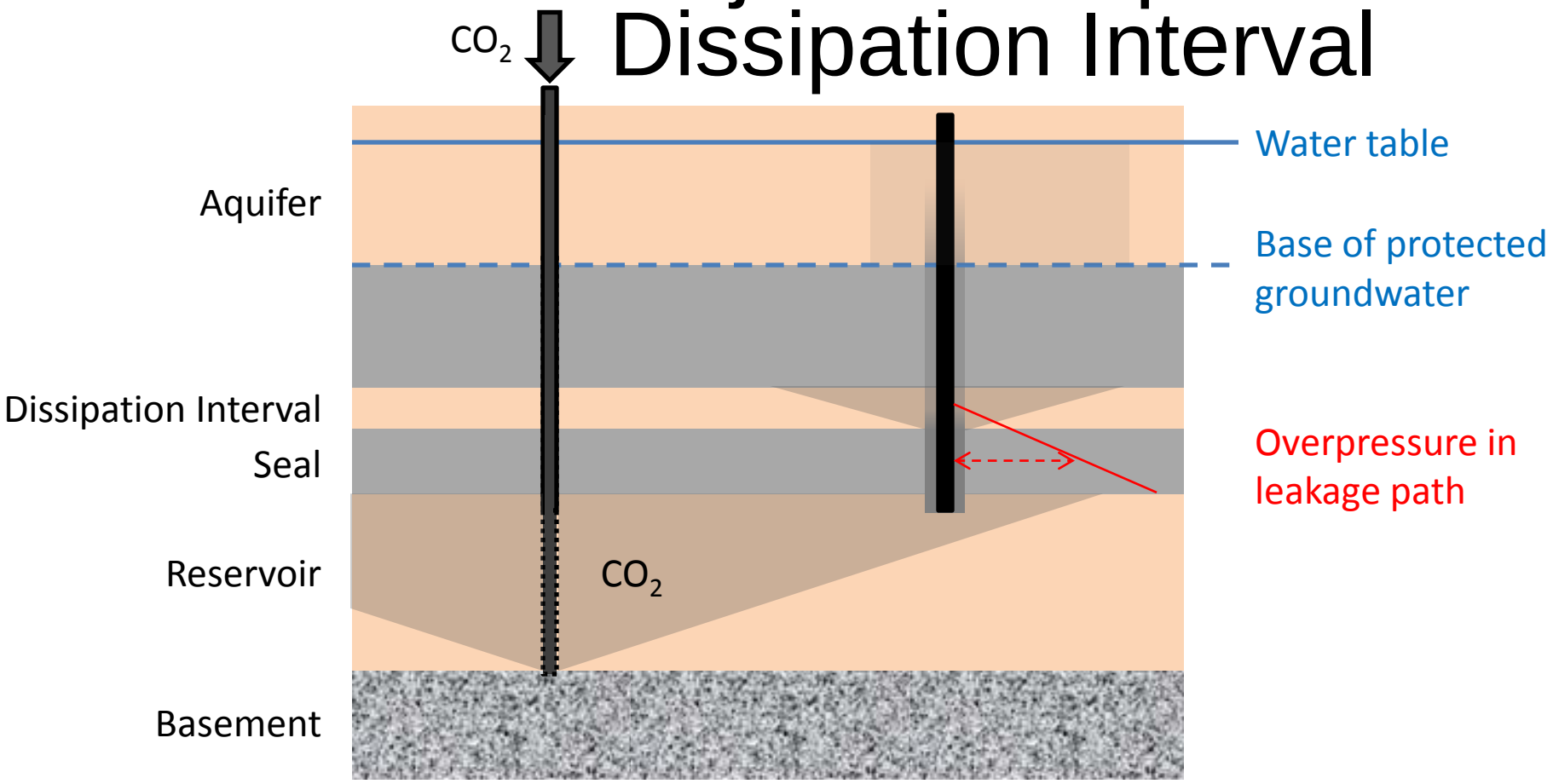
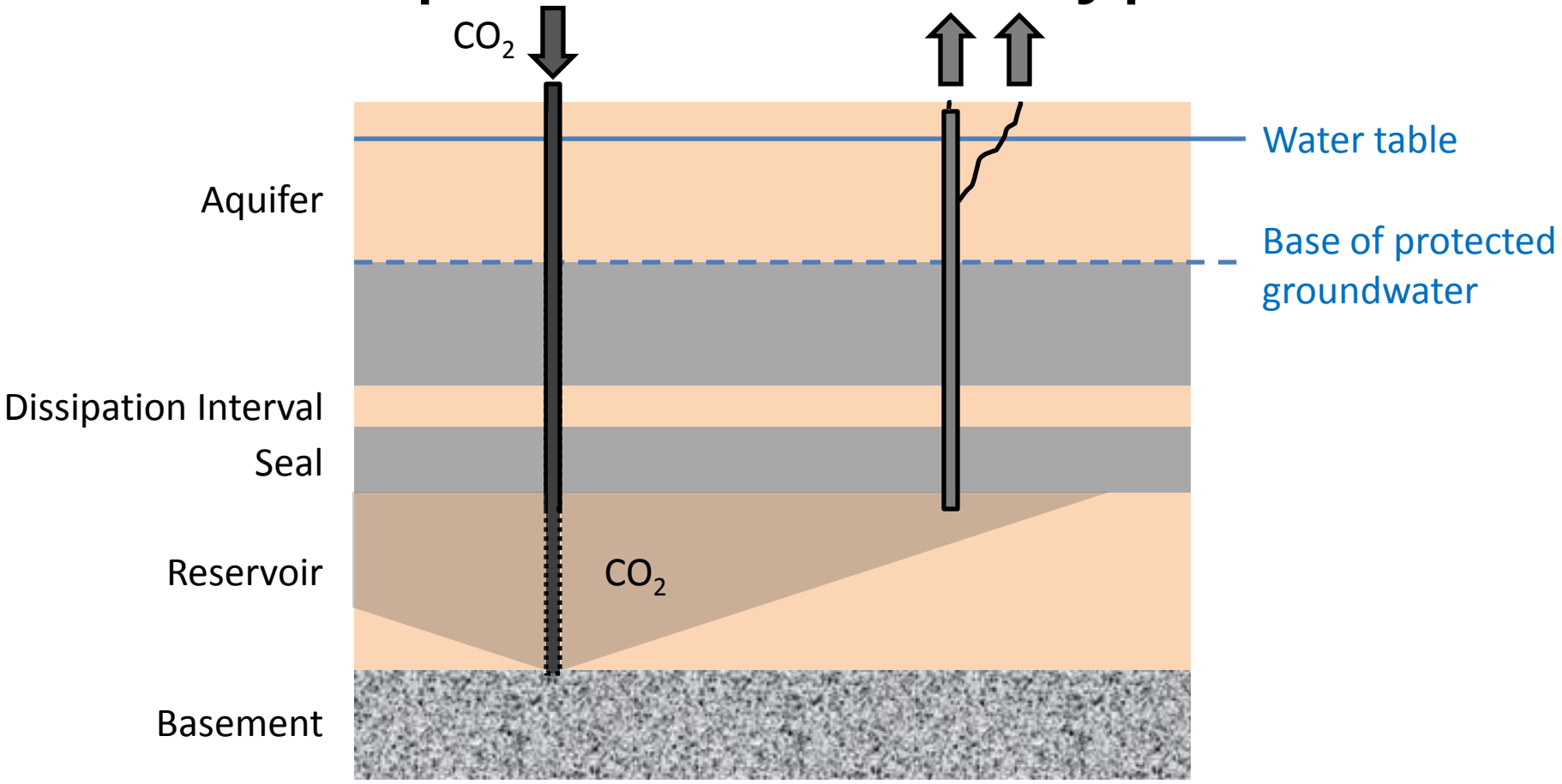


~~Minimum Injection Depth~~ Dissipation Interval

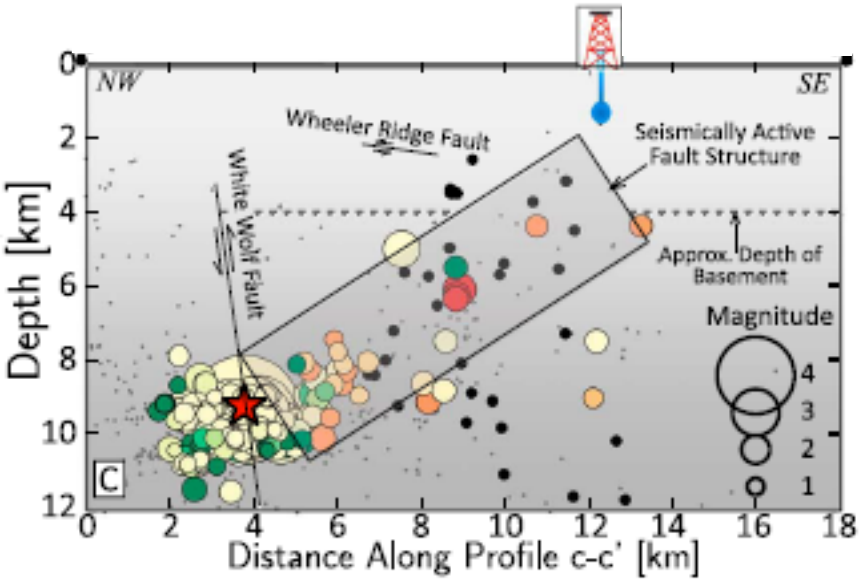


Preference for sites with overlying dissipation interval (transmissivity and capillary entry pressure sufficient to fully dissipate overpressures along hypothetical leakage pathways; similar to AZMI, but with specific hydraulic requirements).

Dissipation Interval Bypass



Seismic Hazard Considerations



Goebel, T. H. W., S. M. Hosseini, F. Cappa, E. Hauksson, J. P. Ampuero, F. Aminzadeh, and J. B. Saleeby (2016), Wastewater disposal and earthquake swarm activity at the southern end of the Central Valley, California, *Geophys. Res. Lett., 43, doi:10.1002/2015GL066948.*

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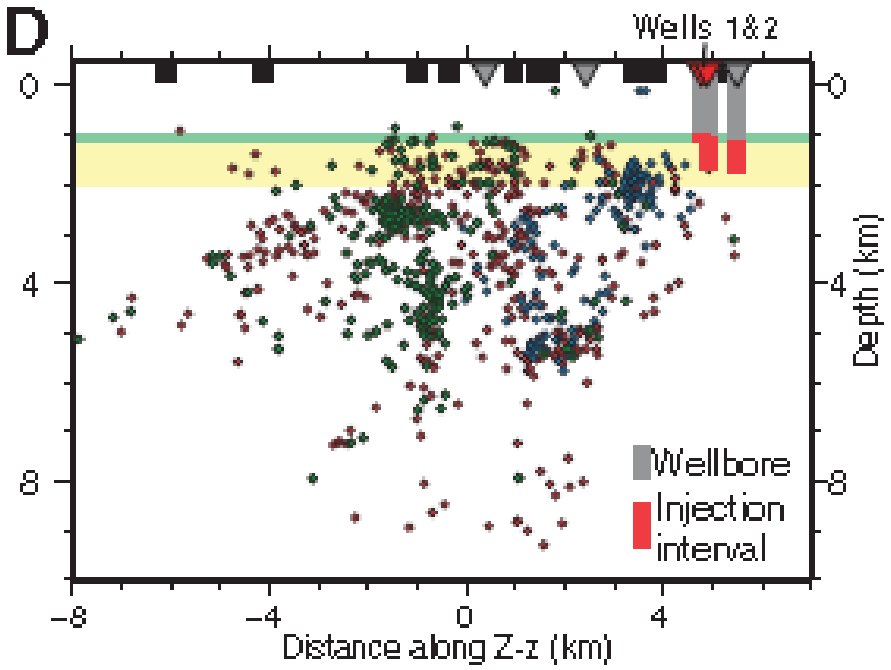

Keranen, K. M., H. M. Savage, G. A. Abers, and E. S. Cochran (2013). Potentially induced earthquakes in Oklahoma, USA: Links between wastewater injection and the 2011 M_w 5.7 earthquake sequence. *Geology*, 41:699-702*, doi:10.1130/G34045.1*.

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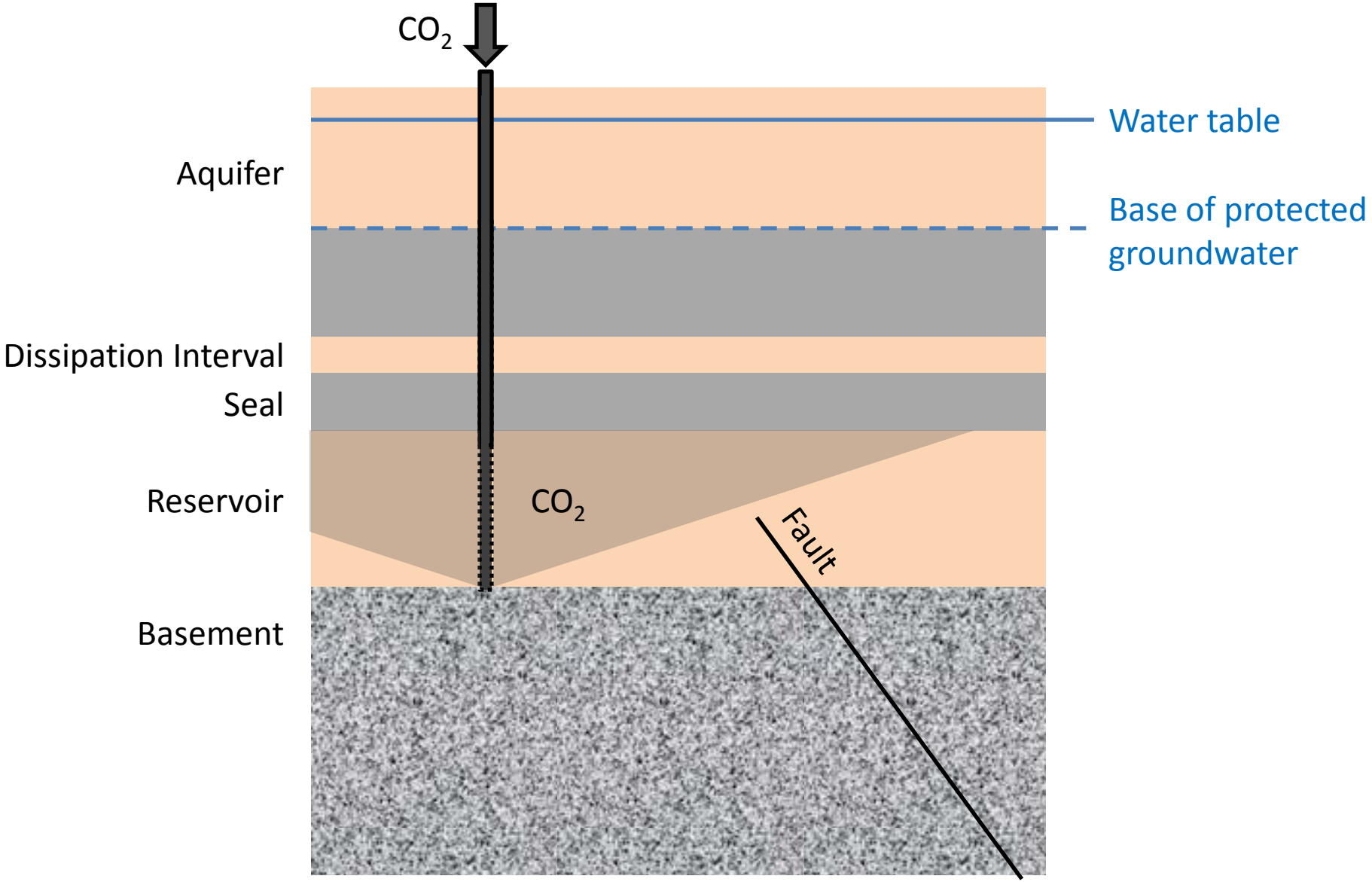

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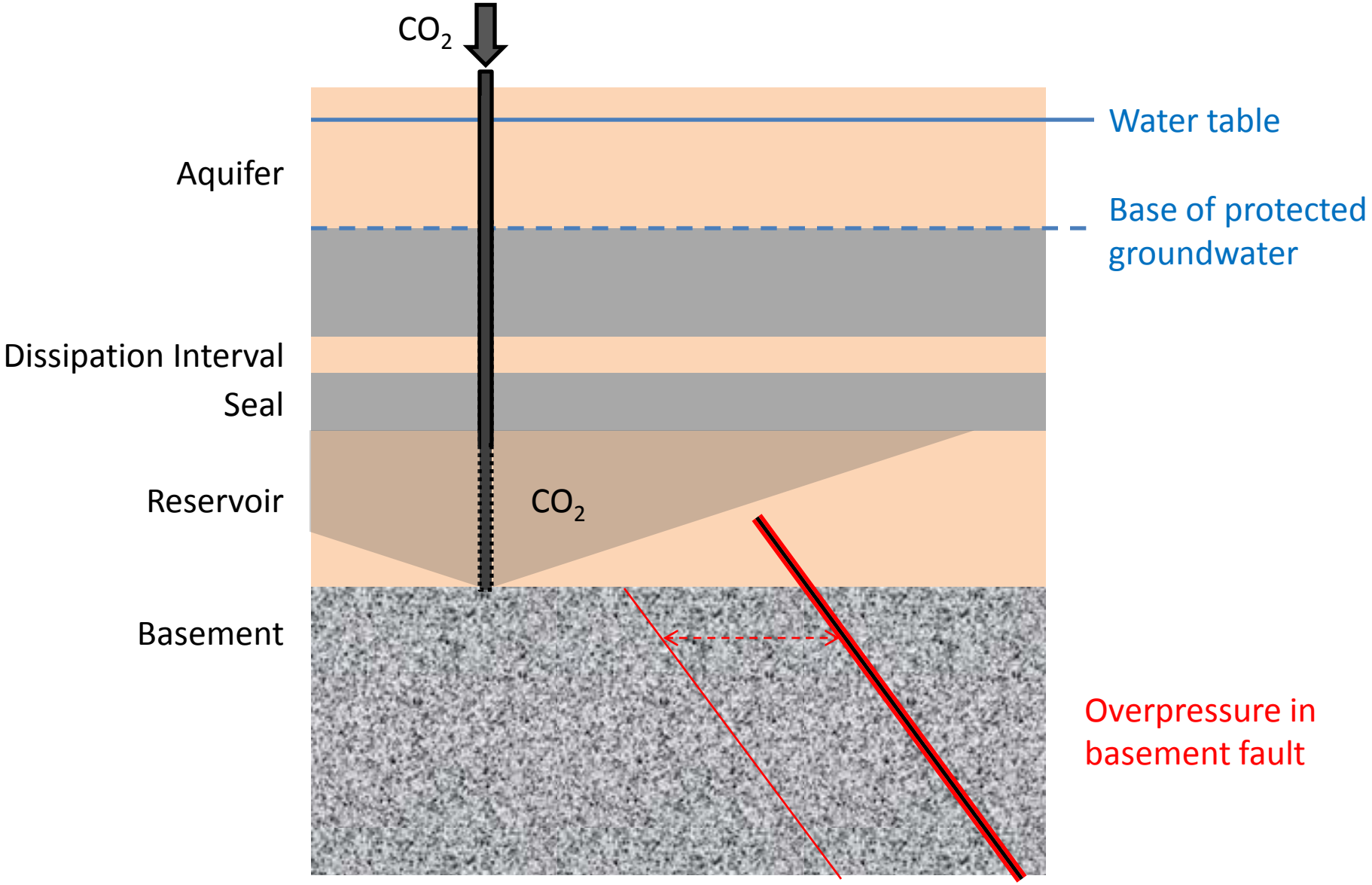

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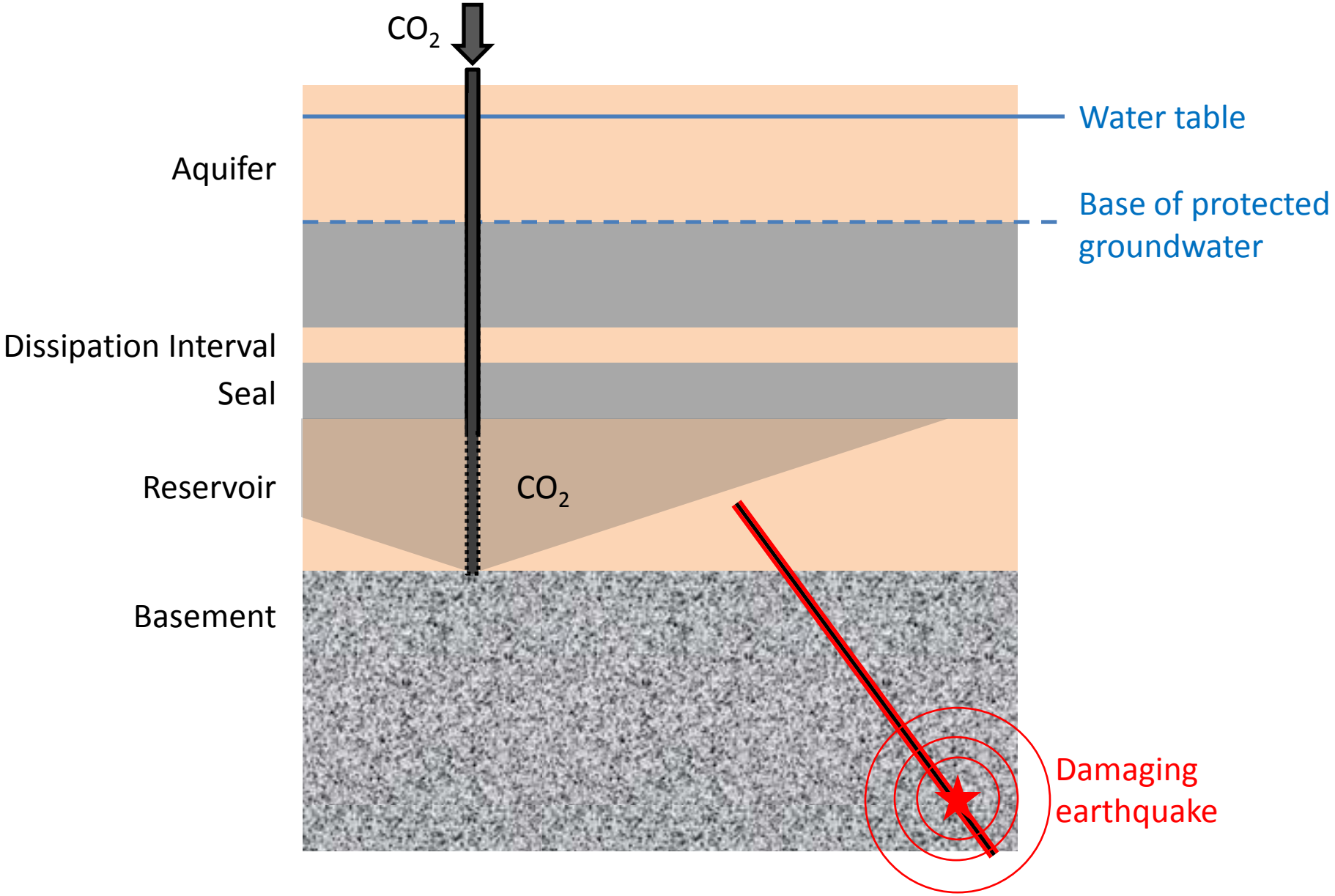

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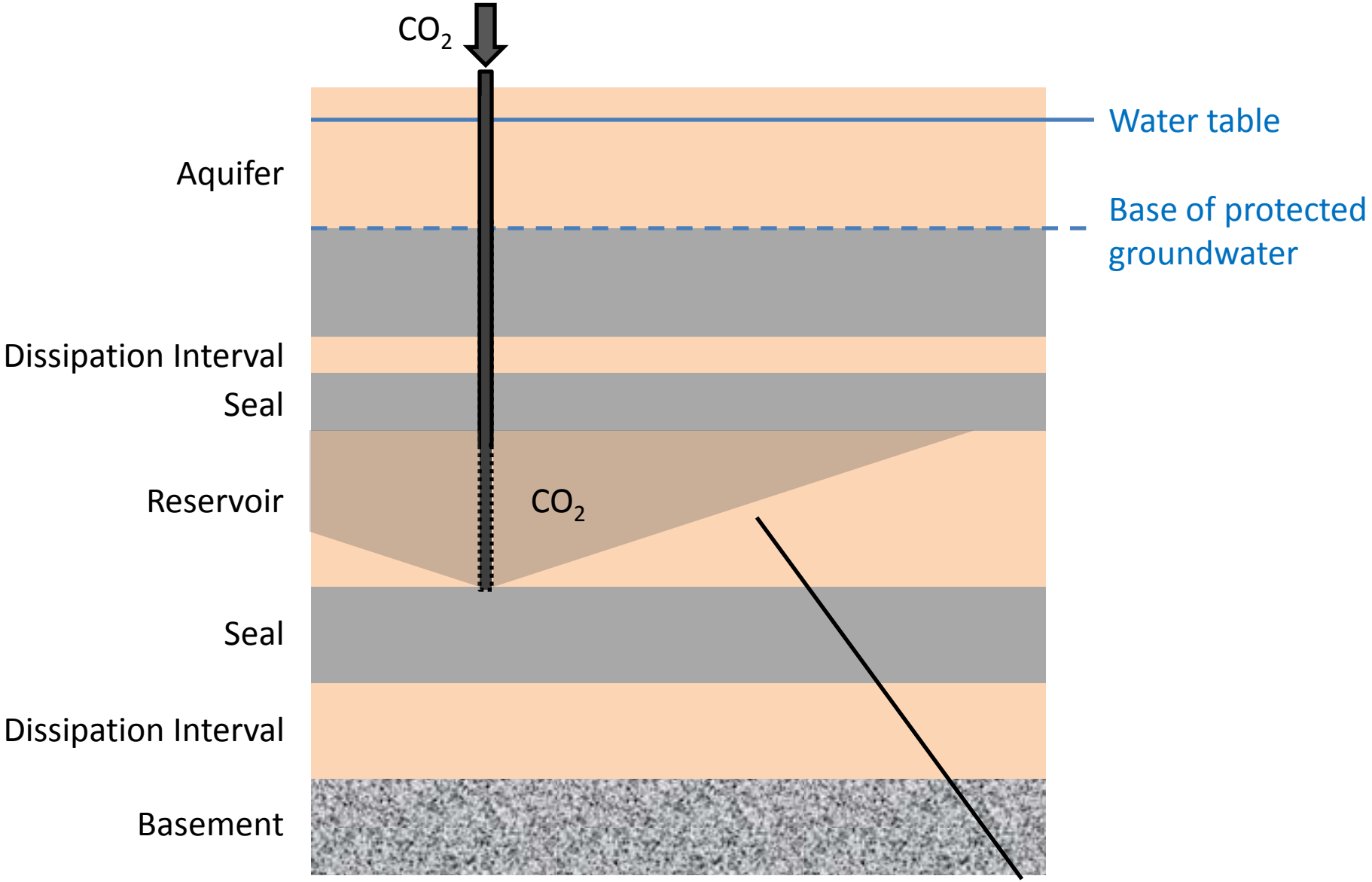

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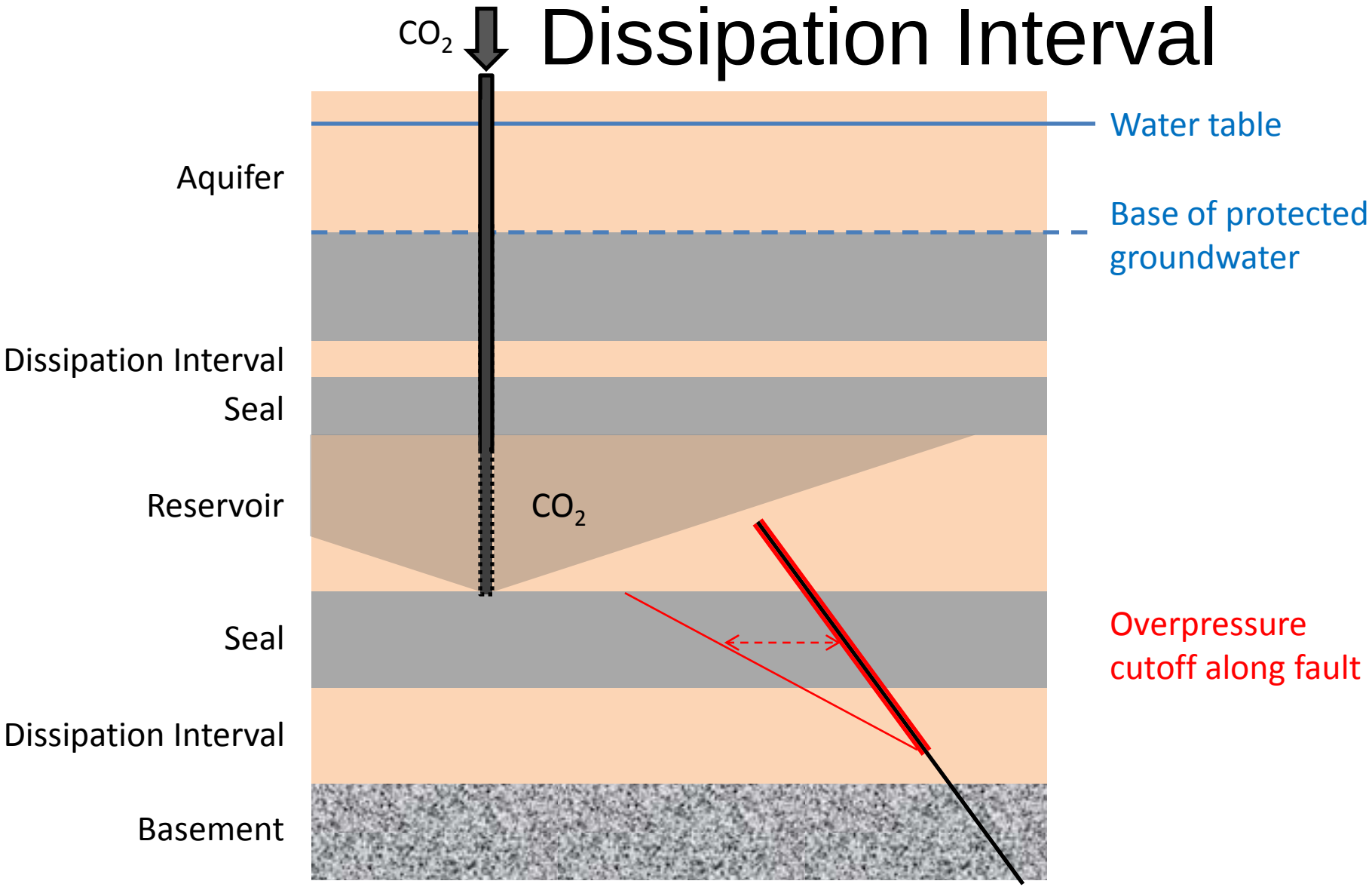
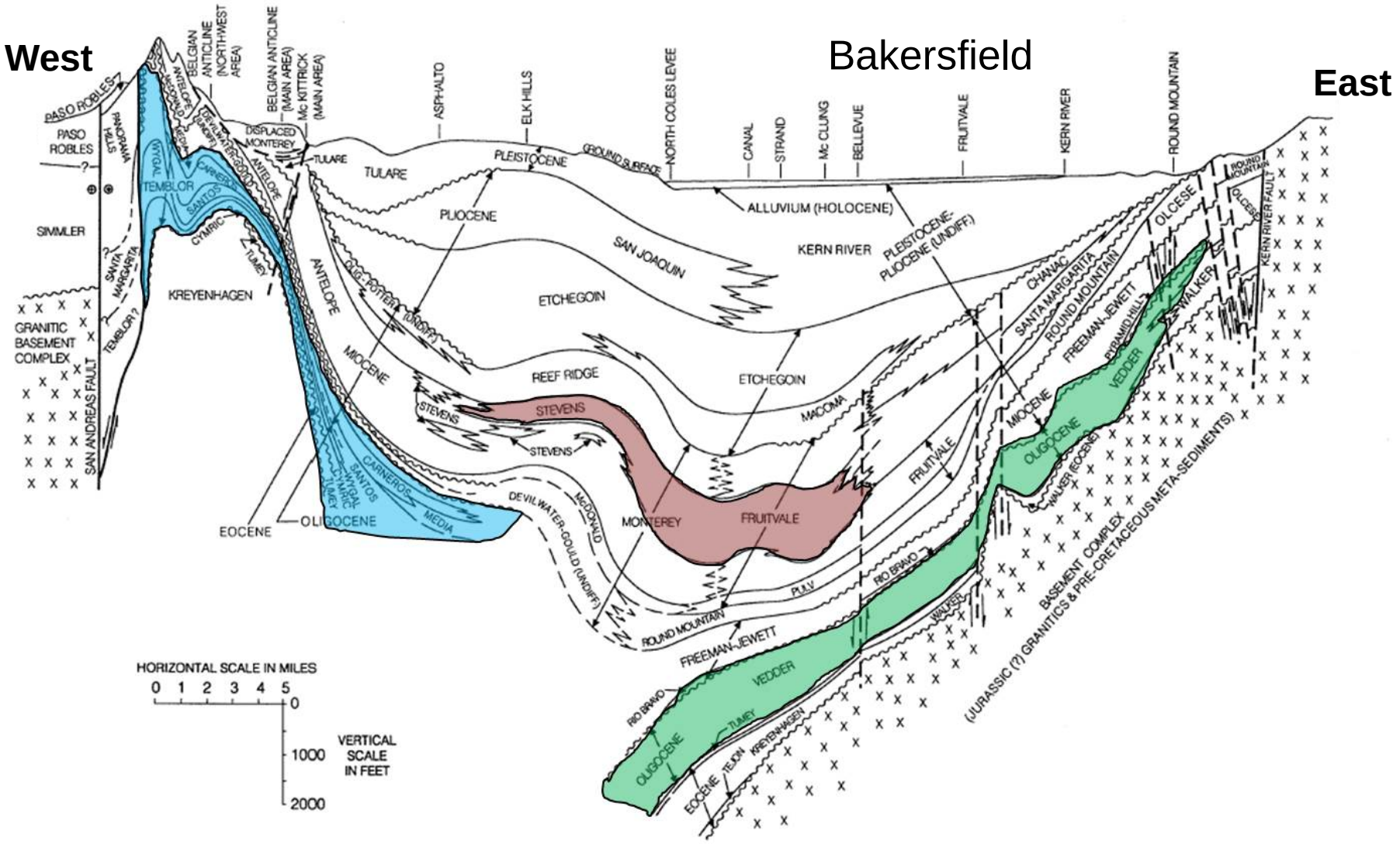
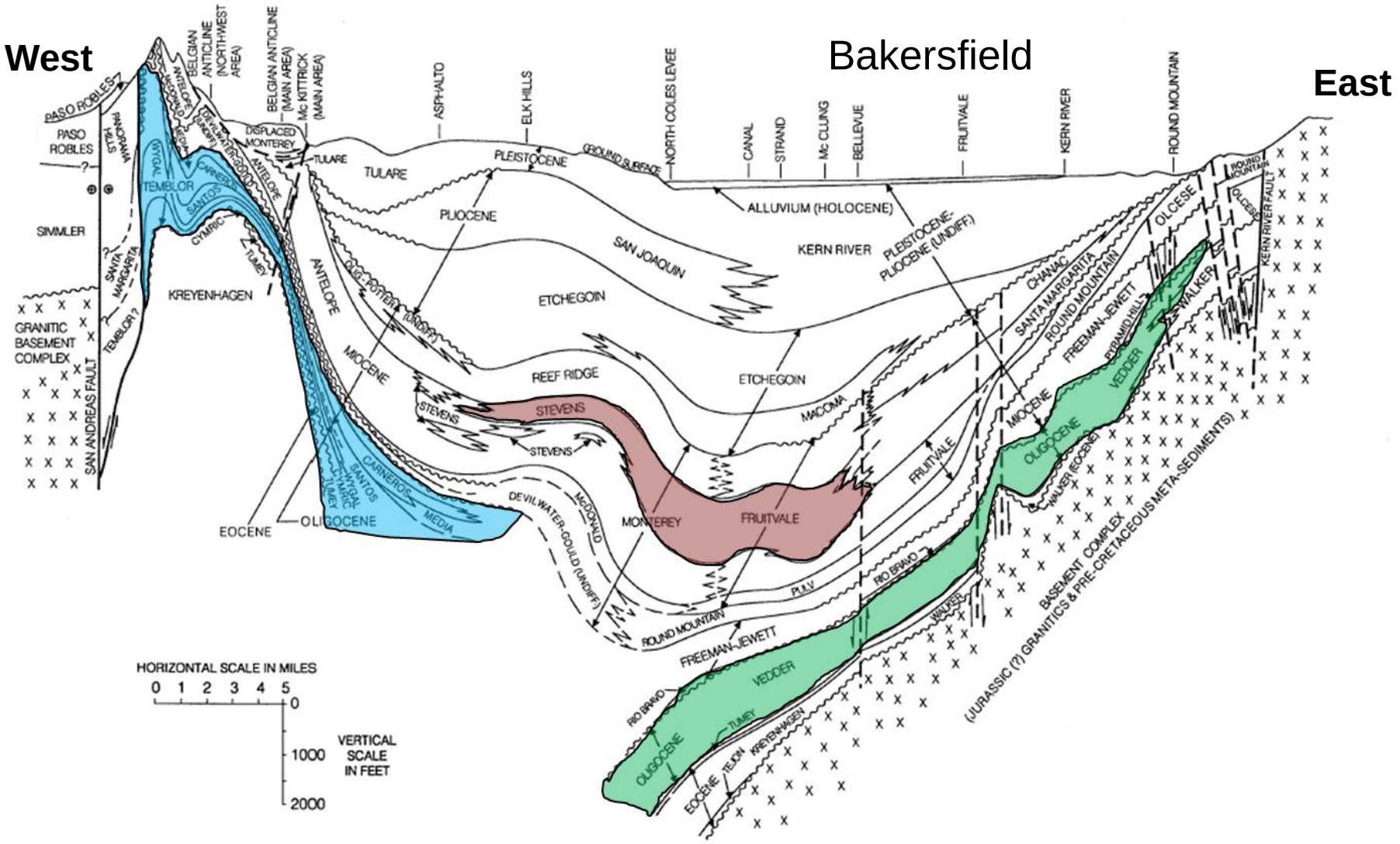


Capacity

Capacity


West
Bakersfield
East
PASO ROBLES
SIMMLER
GRANITIC BASEMENT COMPLEX
SAN ANDREAS FAULT
KREYENHAGEN
TEMBLOR
SANTOS
CARNEROS
MEDIA
CYMRIC
TUMEY
SANTA MARGARITA
ANTELOPE
OLIGOCENE
EOCENE
MIOCENE
PLIOCENE
PLEISTOCENE
TULARE
ALLUVIUM (HOLOCENE)
SAN JOAQUIN
ETCHEGOIN
KERN RIVER
PLEISTOCENE-PLIOCENE (UNDIFF)
REEF RIDGE
STEVENS
MONTEREY
FRUITVALE
MACOMA
CHANAC
ROUND MOUNTAIN
FREEMAN-JEWETT
PYRAMID HILLS
WALKER
VEDDER
OLCESE
KERN RIVER FAULT
DEVILWATER-GOULD (UNDIFF)
McDONALD
PUIV
RIO BRAVO
TEJON
BASEMENT COMPLEX
(JURASSIC (?) GRANITICS & PRE-CRETACEOUS META-SEDIMENTS)
ASPHALTO
ELK HILLS
NORTH COLES LEVEE
CANAL
STRAND
Mc CLUNG
BELLEVUE
FRUITVALE
KERN RIVER
ROUND MOUNTAIN
HORIZONTAL SCALE IN MILES
0 1 2 3 4 5
VERTICAL SCALE IN FEET
0
1000
2000

~~Capacity~~ Injectivity



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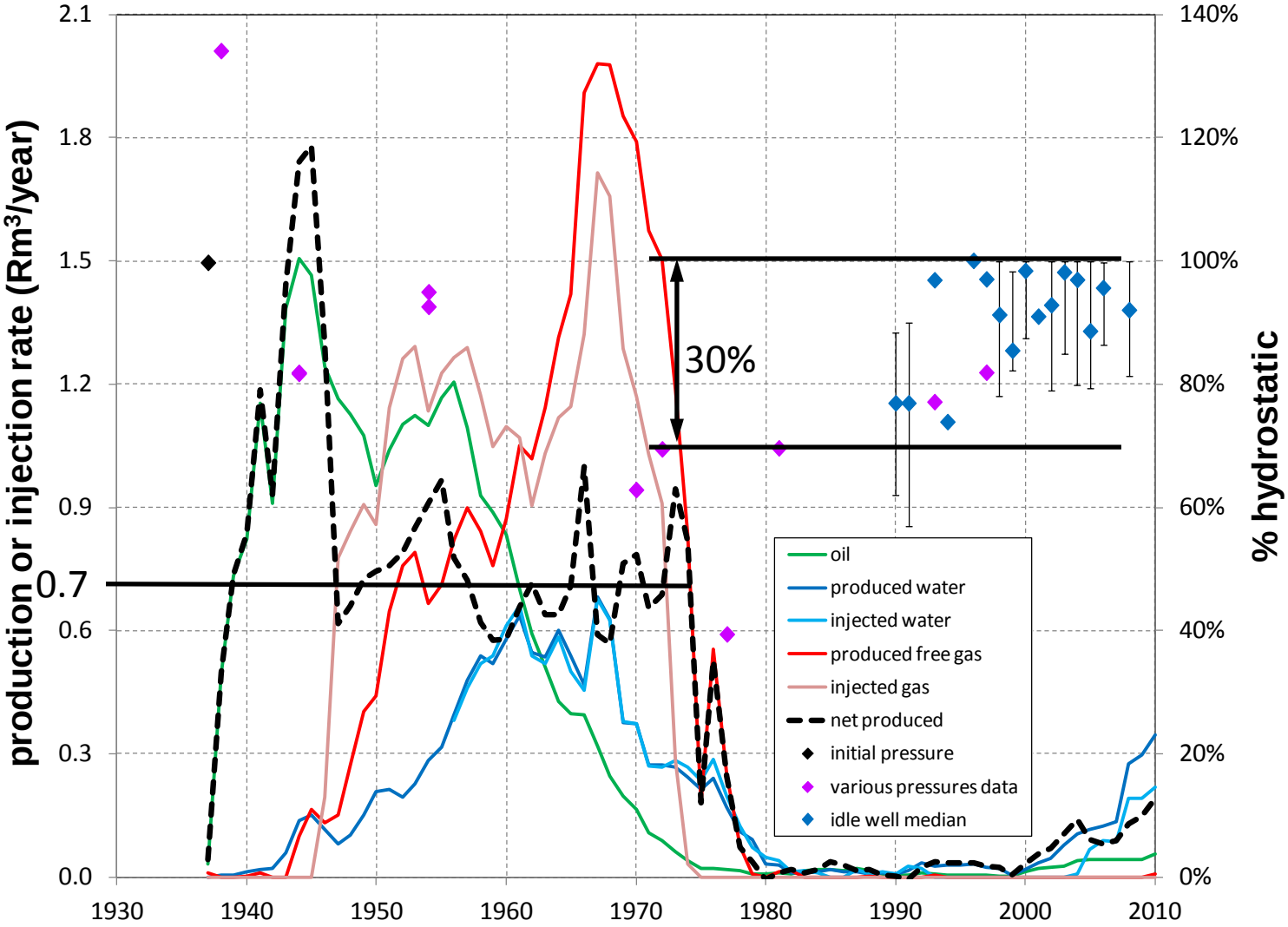


Jordan, P., and J. Gillespie (2013). Potential impacts of future geological storage of CO_2 on the groundwater resources in California's central valley: southern San Joaquin basin oil and gas production analog for geologic carbon storage. Prepared for the California Energy Commission. CEC-500-2014-029. 122 p.

~~Capacity~~ Injectivity

Temblor – ~0.5 Mtpa/100 km^2

Stevens – ~1.5 Mtpa/100 km^2

Vedder – ~2.5 Mtpa/100 km^2

+

Aquifer storage projects to date (including Gorgon)

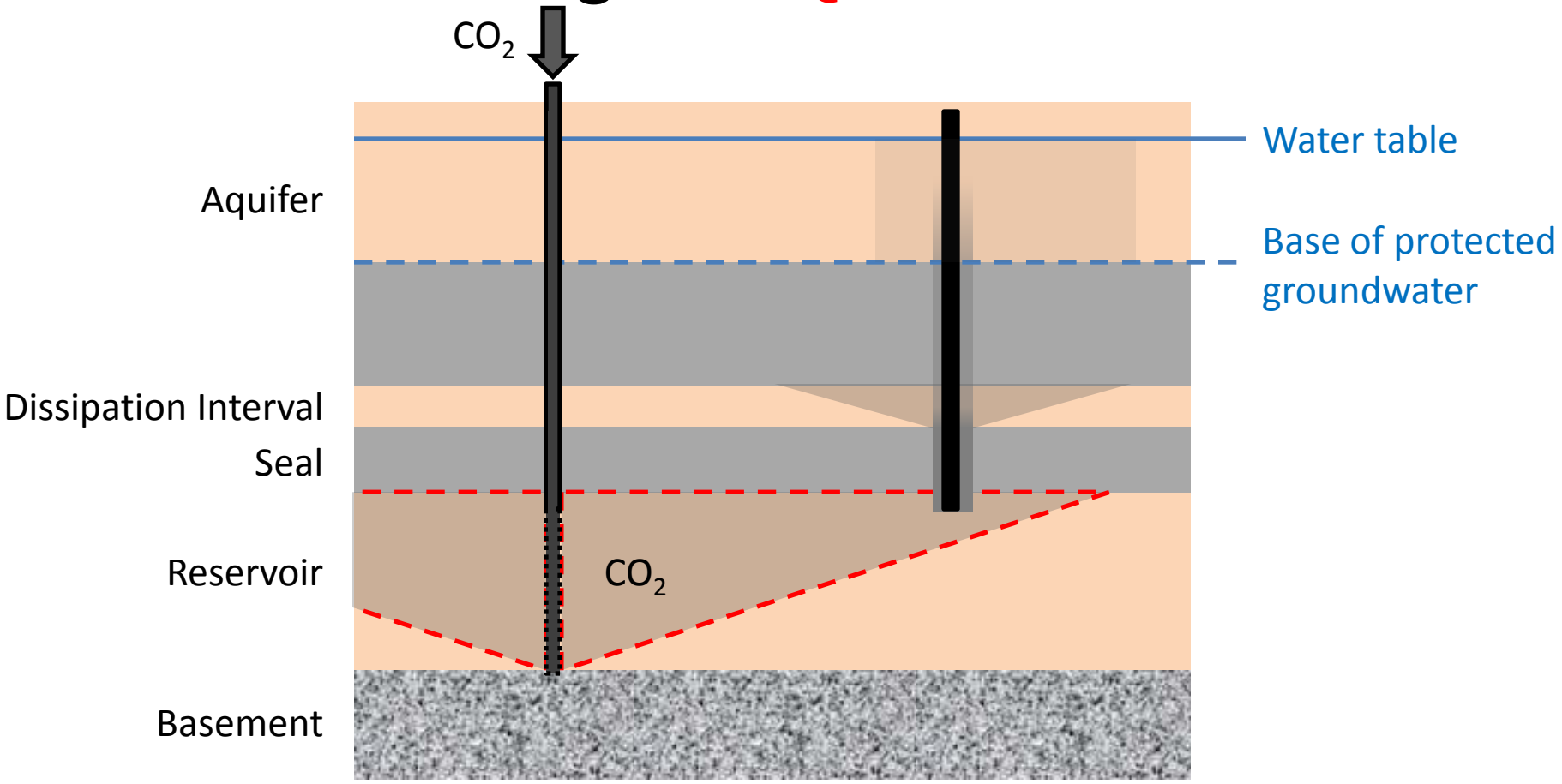
=

Brine production typically needed for power-plant scale injection

Monitoring for Quantification

- strategy for detecting and quantifying surface leakage of CO_2;
- strategy for detecting and monitoring subsurface migration of CO_2;
- strategy for establishing baseline levels of CO_2 emissions;
- technology to be used and the relative merits of the technology (i.e., sensitivity and accuracy);
- area to monitor;
- frequency of measurement;
- spatial coverage in terms of both region and intensity (e.g., number of points per area of ground);
- schedule of monitoring, including phased approaches for different project phases;
- attribution assessment and related monitoring, proxy and/or companion gas monitoring;
- use of gas or groundwater tracers;
- determination of how the monitoring program data can best be utilized to provide annual quantification of the amount of CO_2 stored;
- definition of and techniques to determine CO_2 plume stability.

Monitoring for Quantification



"Positive accounting"

Monitoring for Quantification

>10% as calculated from porosity and reservoir volume

$$\frac{\Delta I}{I} = \frac{\Delta V}{V} + \frac{\Delta p}{p} + \frac{\Delta z}{z} + \frac{\Delta T}{T}$$

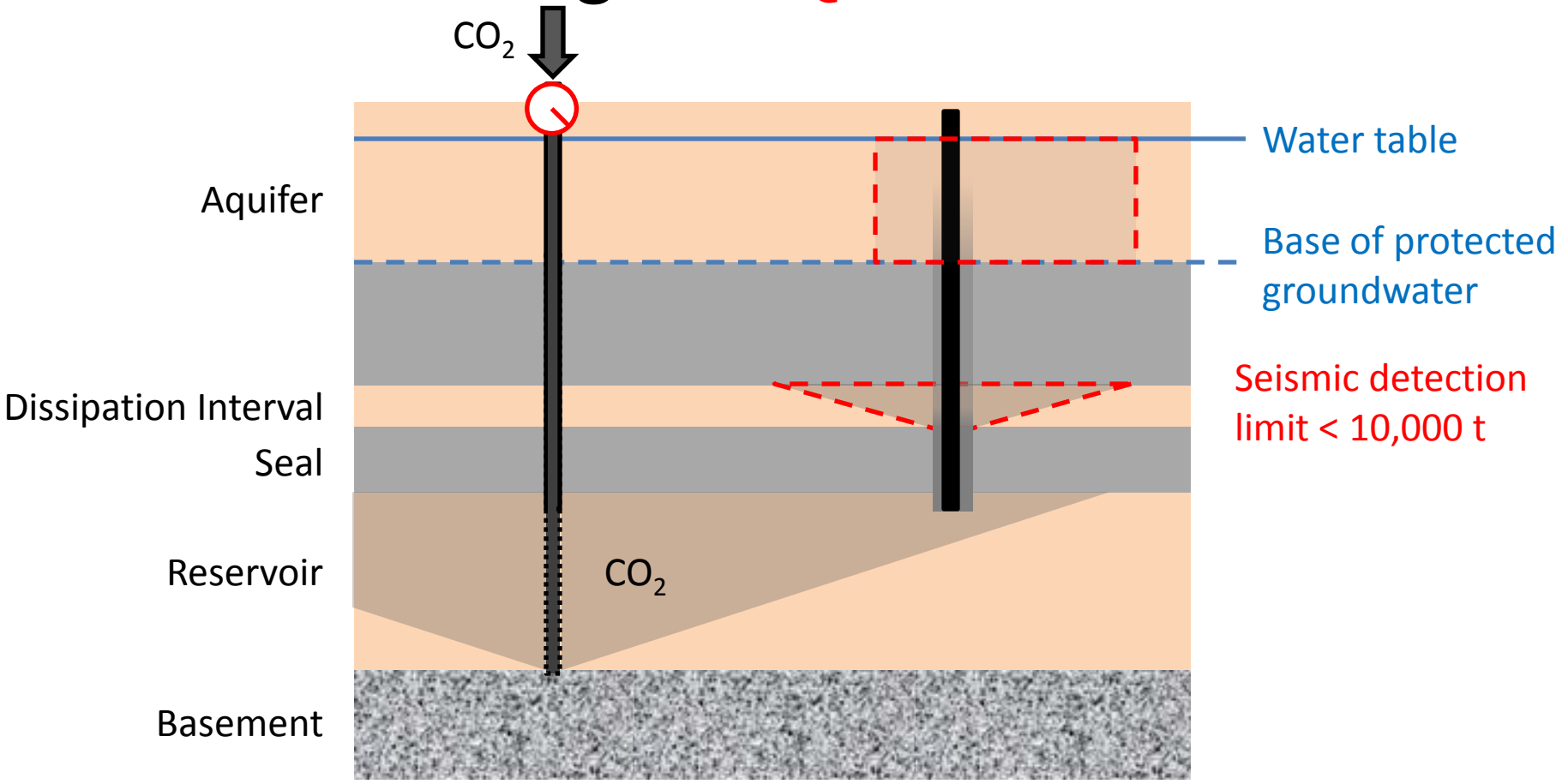
>15%

>2% in total

Uncertainty in “positive accounting”
>150,000 Mt on 1 MMt for example

Modified from Tek, M. R. (1991). Errors and uncertainty in inventory verification in underground storage. SPE manuscript 23829. 24 pp. Available at https://www.onepetro.org/download/general/SPE-23829-MS?id=general%2FSPE-23829-MS.

Monitoring for Quantification



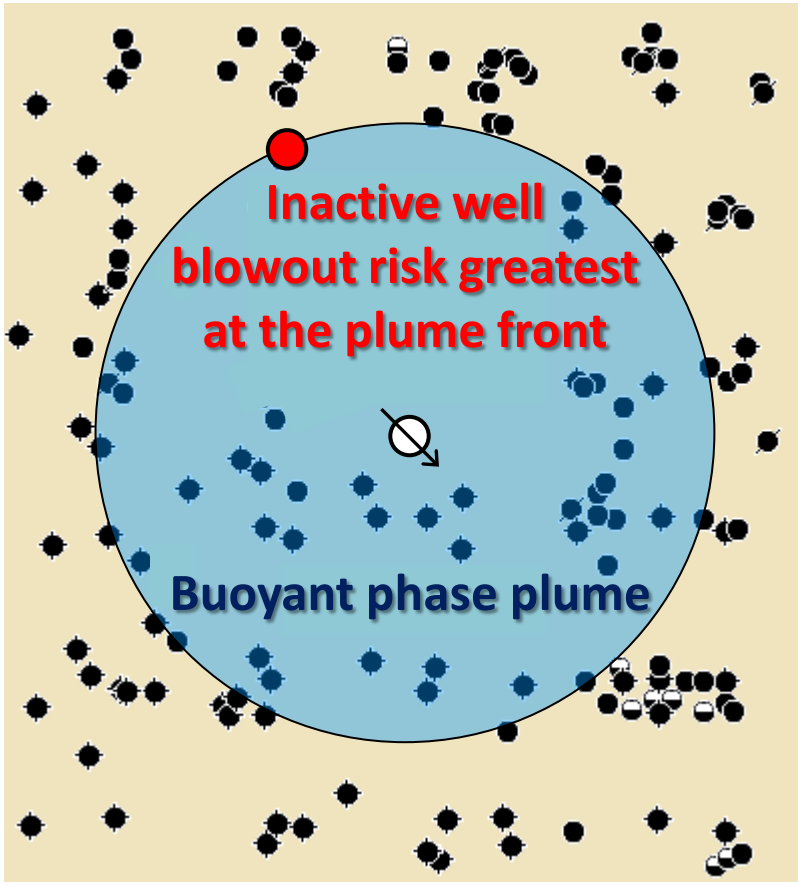
"Negative accounting"

Hoversten, M. E. Gasperikova, and S. M. Benson (2005). Theoretical Limits for Seismic Detection of Small Accumulations of Carbon Dioxide in the Subsurface. LBNL Report No. 59080. Presented at GHGT-8, 19-22 June 2006 in Trondheim, Norway.

Monitoring for Quantification

Recommend “negative accounting”

Monitoring for Quantification



Start of chronic well leakage most likely at the plume front

Watson, T. L, and S. Bachu (2007) Evaluation of the potential for gas and CO_2 leakage along wellbores. SPE Drilling \& Completion, March:115-126.

Leakage exterior to casing likely results in secondary accumulation,

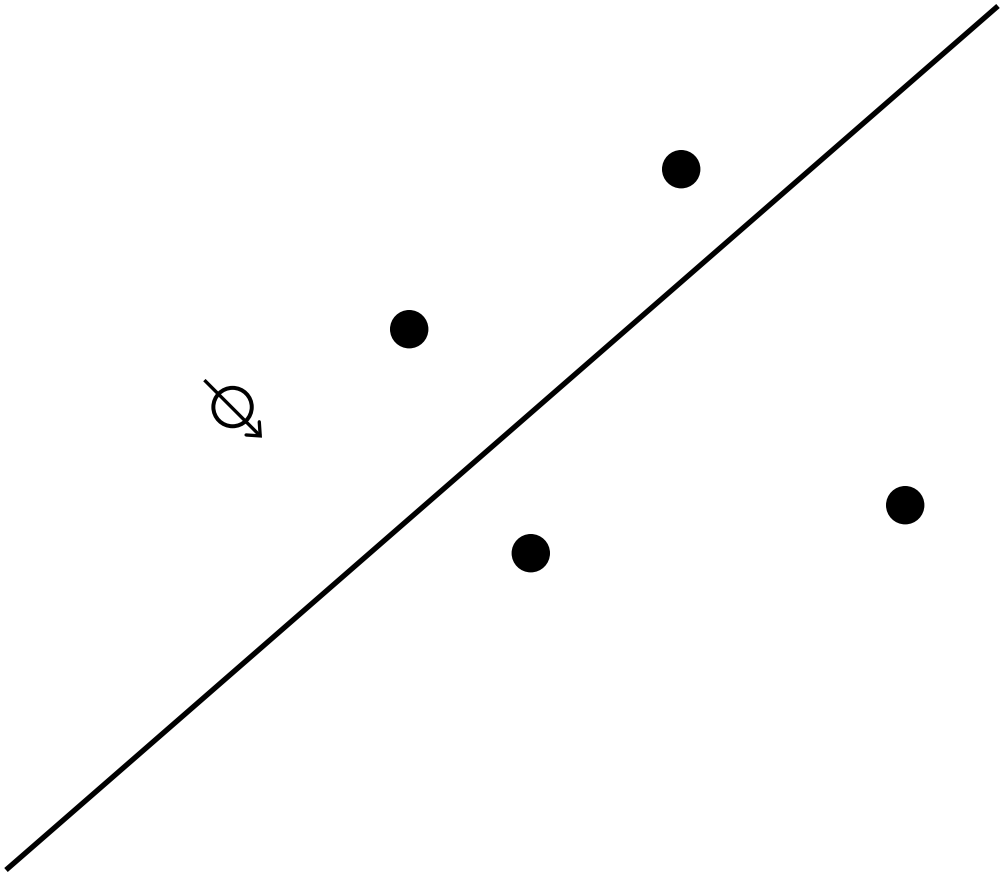
McKenna, G.T. (1995). Grouted-in installation of piezometers in boreholes. *Canadian Geotechnical Journal*, 32:355-363.

And likely decreases through time.

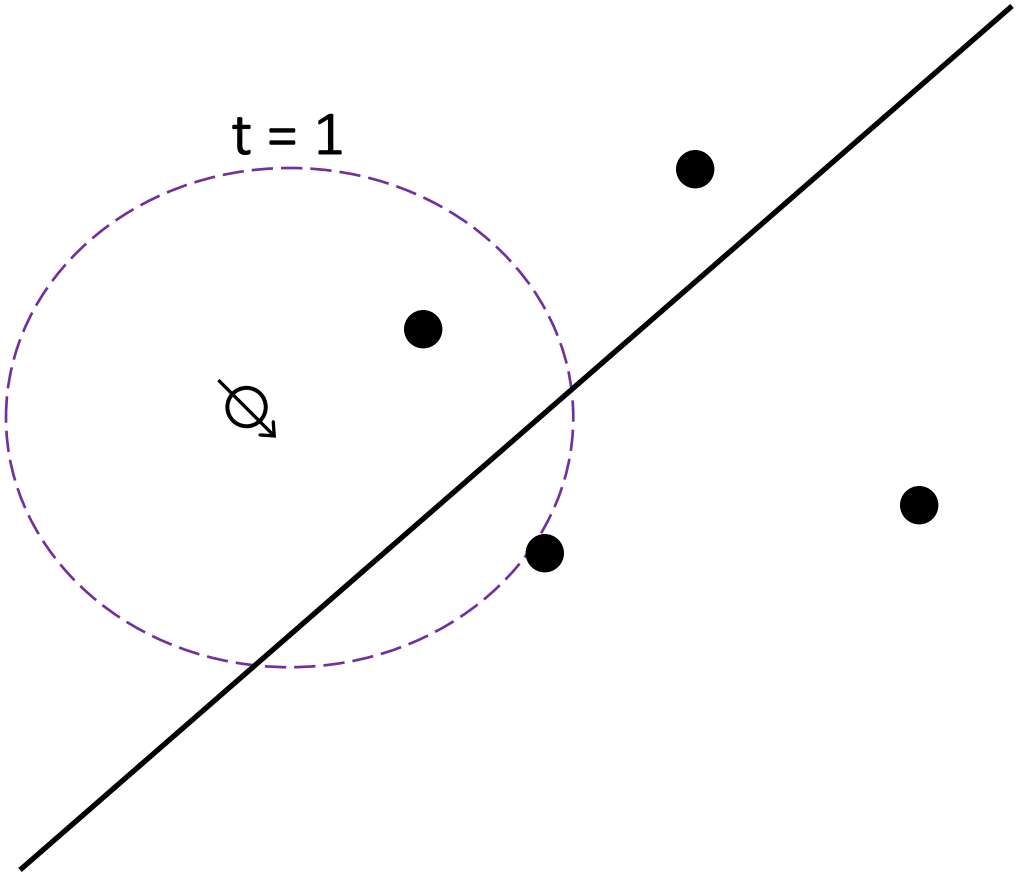
Brunet, J.-P.L. , L. Li, Z.T. Karpyn, and N.J. Huerta (2016). Cement fracture opening or self-sealing: critical residence time unifies diverging observations under geological carbon sequestration conditions. *Int. J. Greenh. Gas Control* 47: 25-37. http://dx.doi.org/10.1016/j.ijggc.2016.01.024

Jordan, P.D., and J. W. Carey (2016). Steam blowouts in California Oil and Gas District 4: Comparison of the roles of initial defects versus well aging and implications for well blowouts in geologic carbon storage projects. *Int. J. Greenh. Gas Control* , 51:36-47.

Monitoring for Quantification

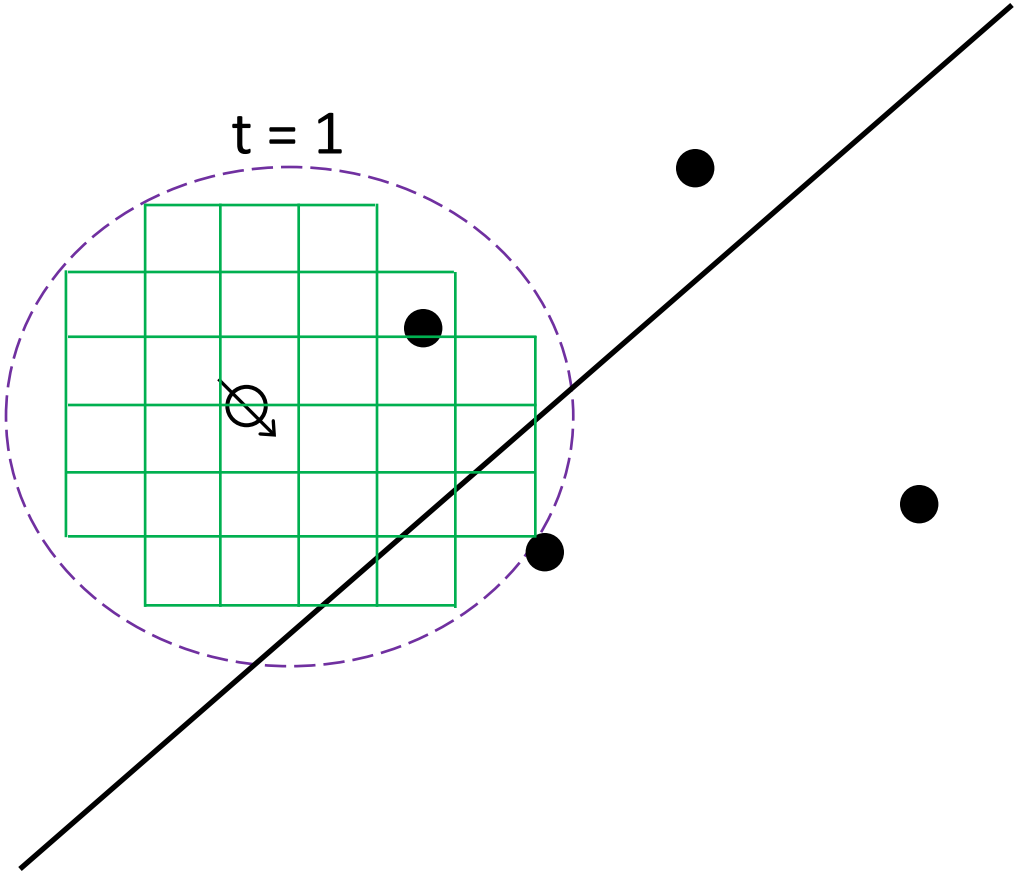


Monitoring for Quantification



Plume: remote sensing

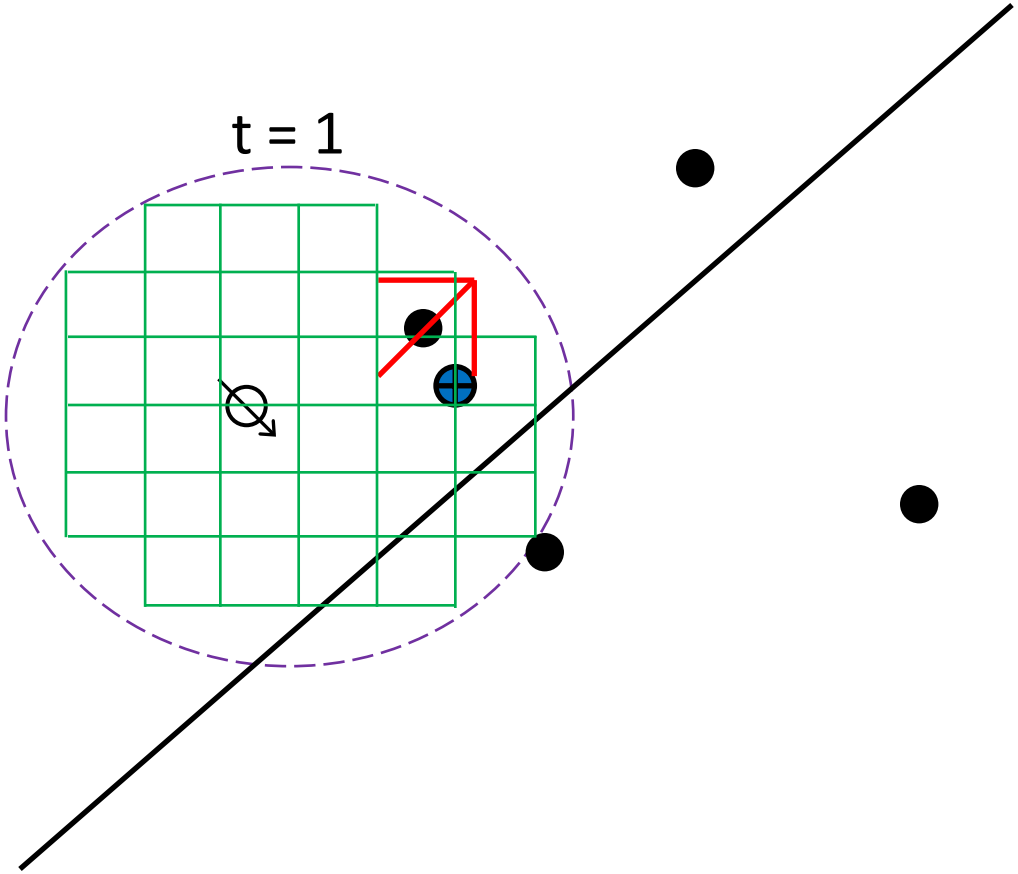
Monitoring for Quantification



Plume: remote sensing

Plume front: surface geophysics

Monitoring for Quantification

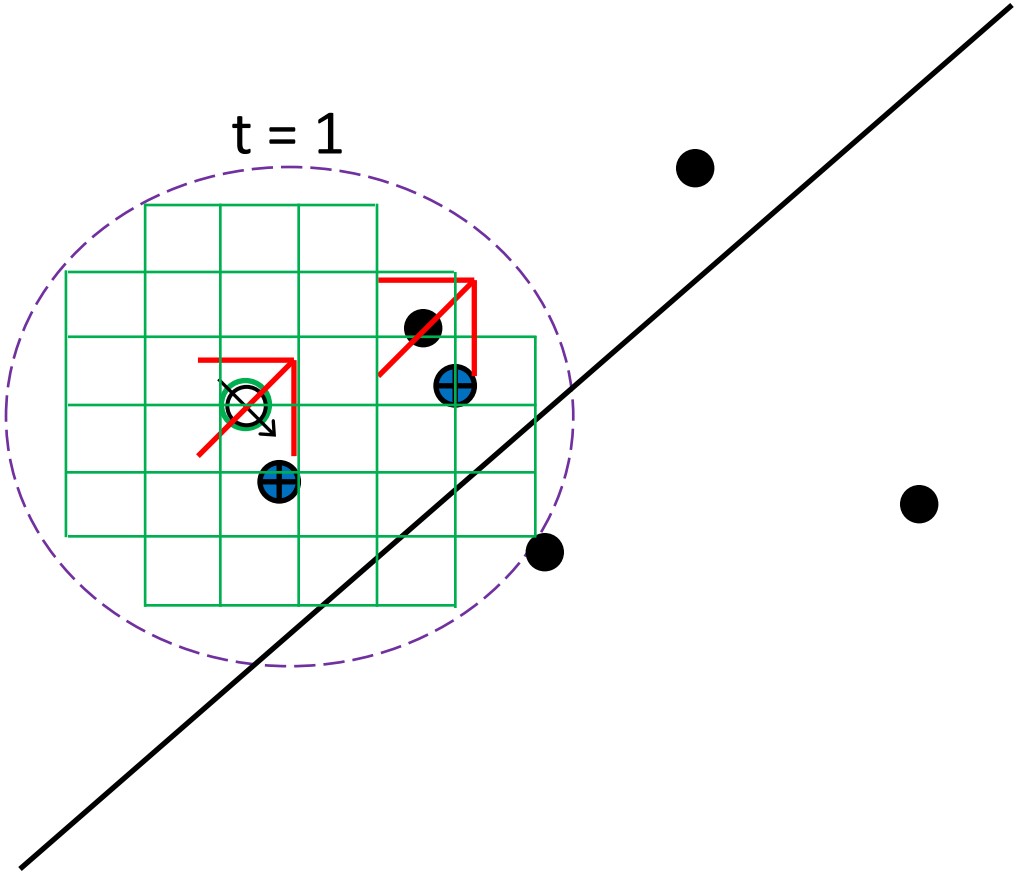


Plume: remote sensing

Plume front: surface geophysics

Prior wells at plume front: atmospheric, groundwater

Monitoring for Quantification



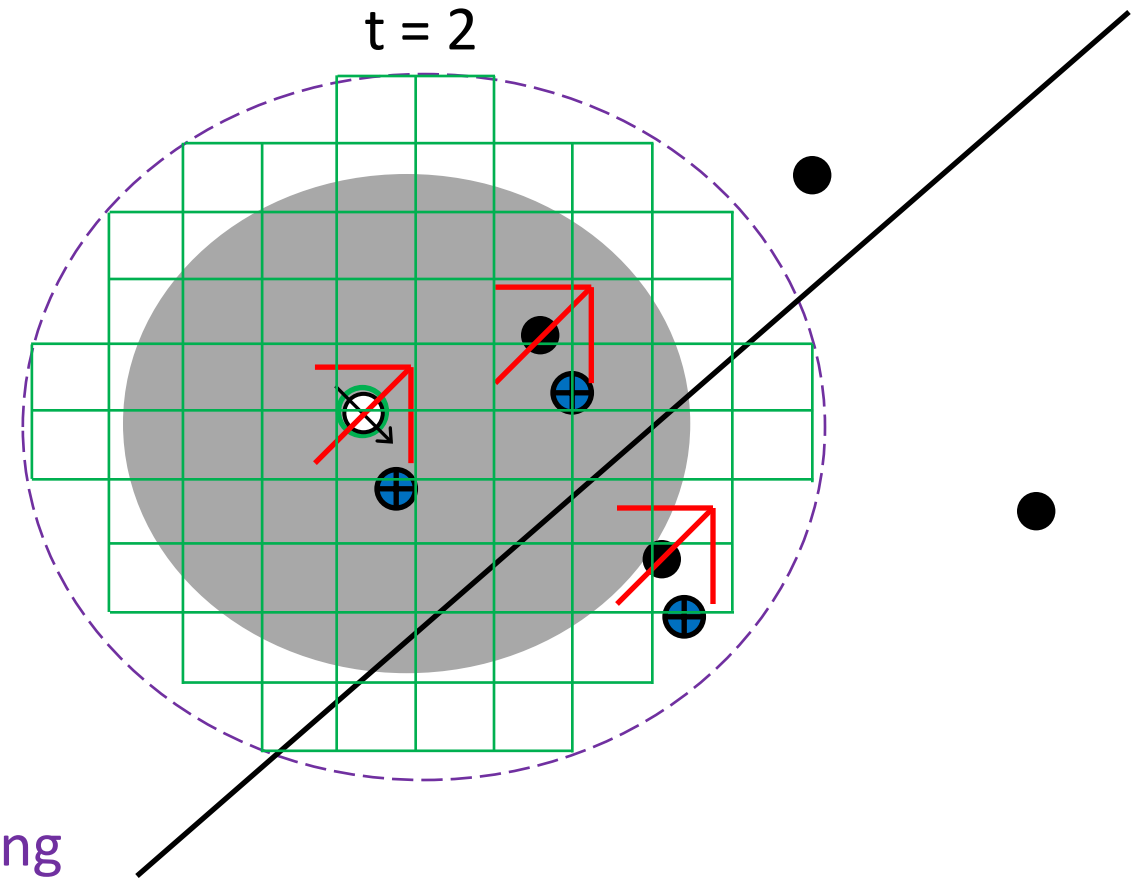
Plume: remote sensing

Plume front: surface geophysics

Prior wells at plume front: atmospheric, groundwater

Injector(s): atmospheric, groundwater, downhole geophysics

Monitoring for Quantification



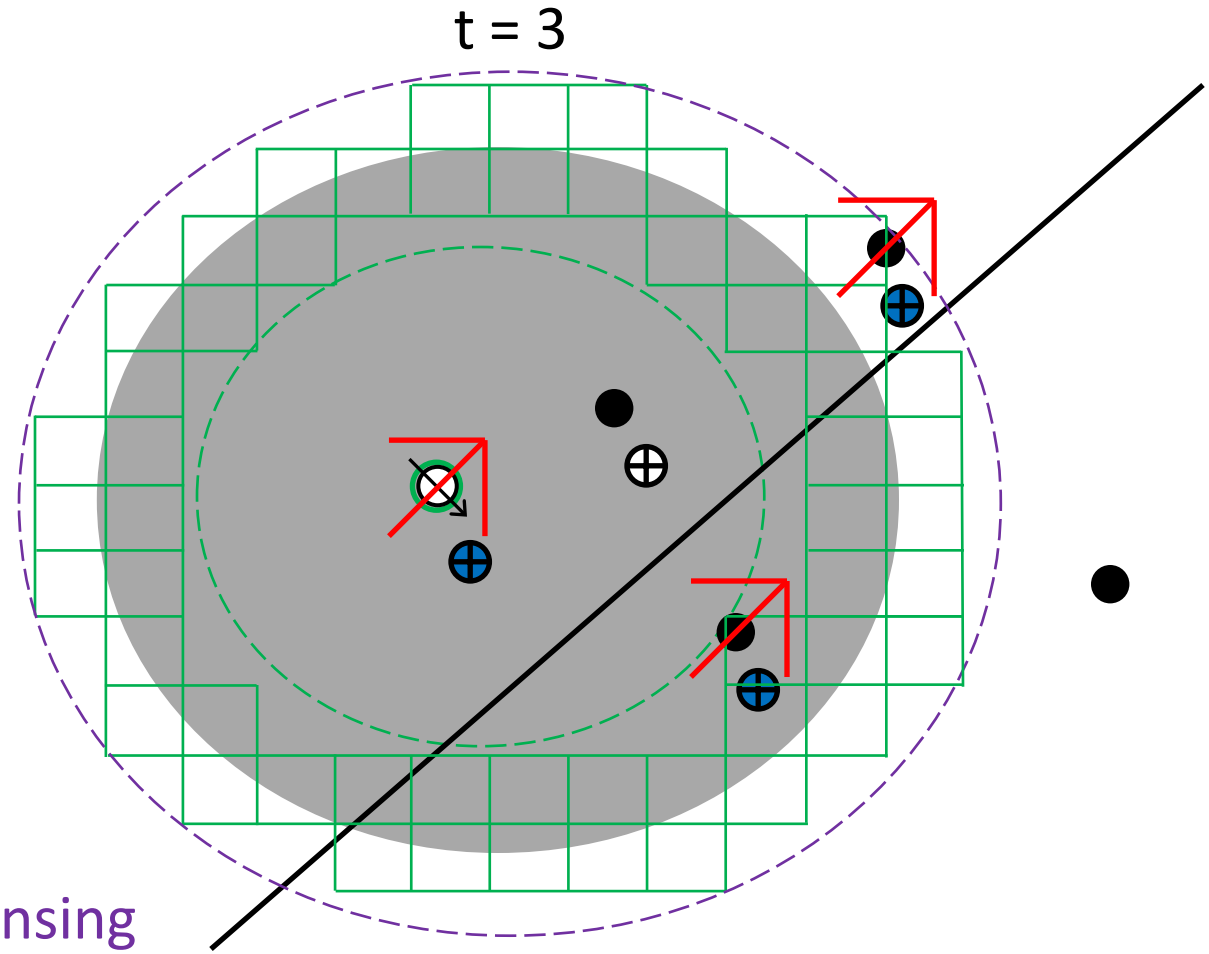
Plume: remote sensing

Plume front: surface geophysics

Prior wells at plume front: atmospheric, groundwater

Injector(s): atmospheric, groundwater, downhole geophysics

Monitoring for Quantification



Plume: remote sensing

Plume front: surface geophysics

Prior wells at plume front: atmospheric, groundwater

Injector(s): atmospheric, groundwater, downhole geophysics