Perchlorate as an Example of Groundwater Contamination Arising from Dense Brines

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Presentation Pathway

- Perchlorate as a brine
- Other contaminants present in brines
- Two field examples
- Brine transport processes – experimental
- Brine transport processes – predictions
- Return to field examples
- Summary

Ammonium Perchlorate: NH_4ClO_4

Released during production and rocket hogging out

Solubility: 180 g ClO_4^-/L

Saturated Fluid Density: 1.11 g/cm^3

Largely non-reactive (tracer)

California Public Health Goal: 6 µg/L

Volume required to dilute saturated solution to Public Health Goal:

$$\approx \frac{180\, g / L}{6\, \mu g / L} = 3 \times 10^7$$

Common Brine Occurrences

Occurrence	Source	Density [g/cm^3]	Cont.	Reported Conc.	MCL	Dilution Required
Acid Mine	H_2SO_4	1.4	As	340 mg/L	10 μg/L	10^5
Landfill Leachate	TDS	1.05	Vinyl Chloride	40 mg/L	2 μg/L	10^4
Nuclear Fuel Reprocessing	$NaNO_3$	1.5	^{90}Sr	4×10^{10} Bq/L	10 Bq/L	10^{10}
			^{137}Cs	8×10^9 Bq/L	50 Bq/L	10^8
Solid Rocket Fuel	NH_4ClO_4	1.11	ClO_4^-	180 g/L (*solubility*)	6 μg/ L	10^7

Acid Mine

Landfill

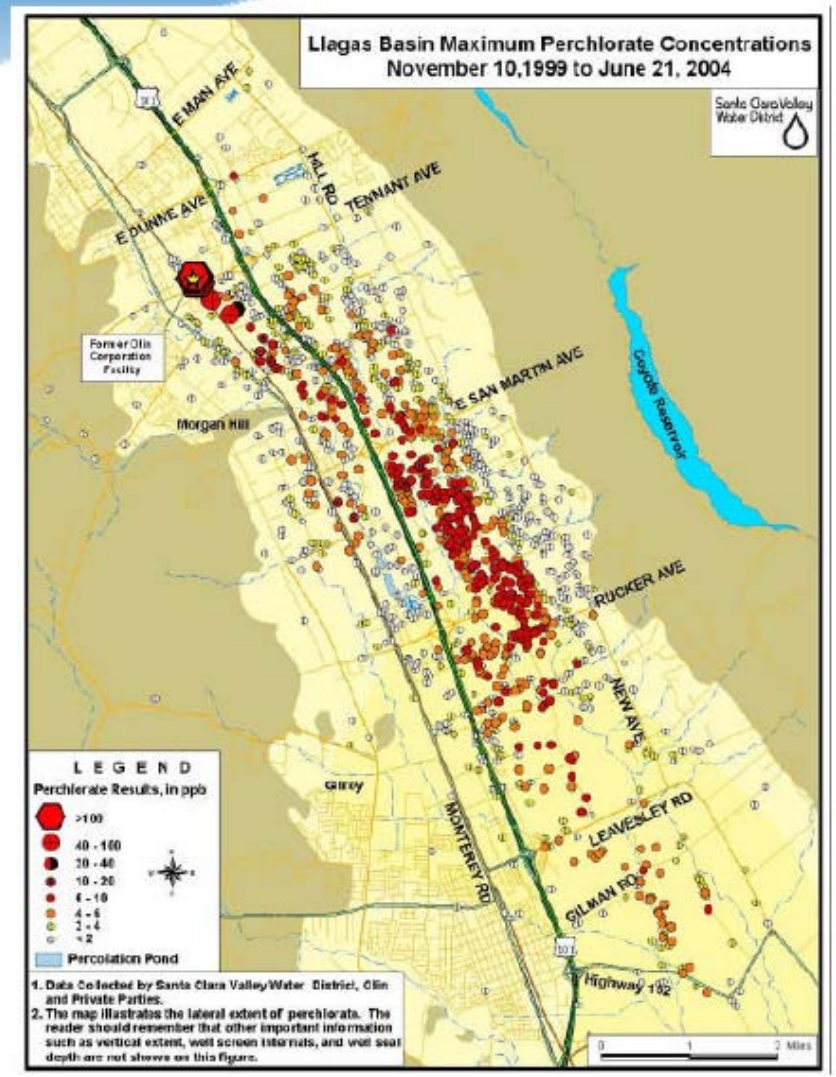
Nuclear Fuel Reprocessing

Solid Rocket Fuel

Example 1: Olin Facility, Morgan Hill, CA

Perchlorate Occurrence (as of 6/15/04)

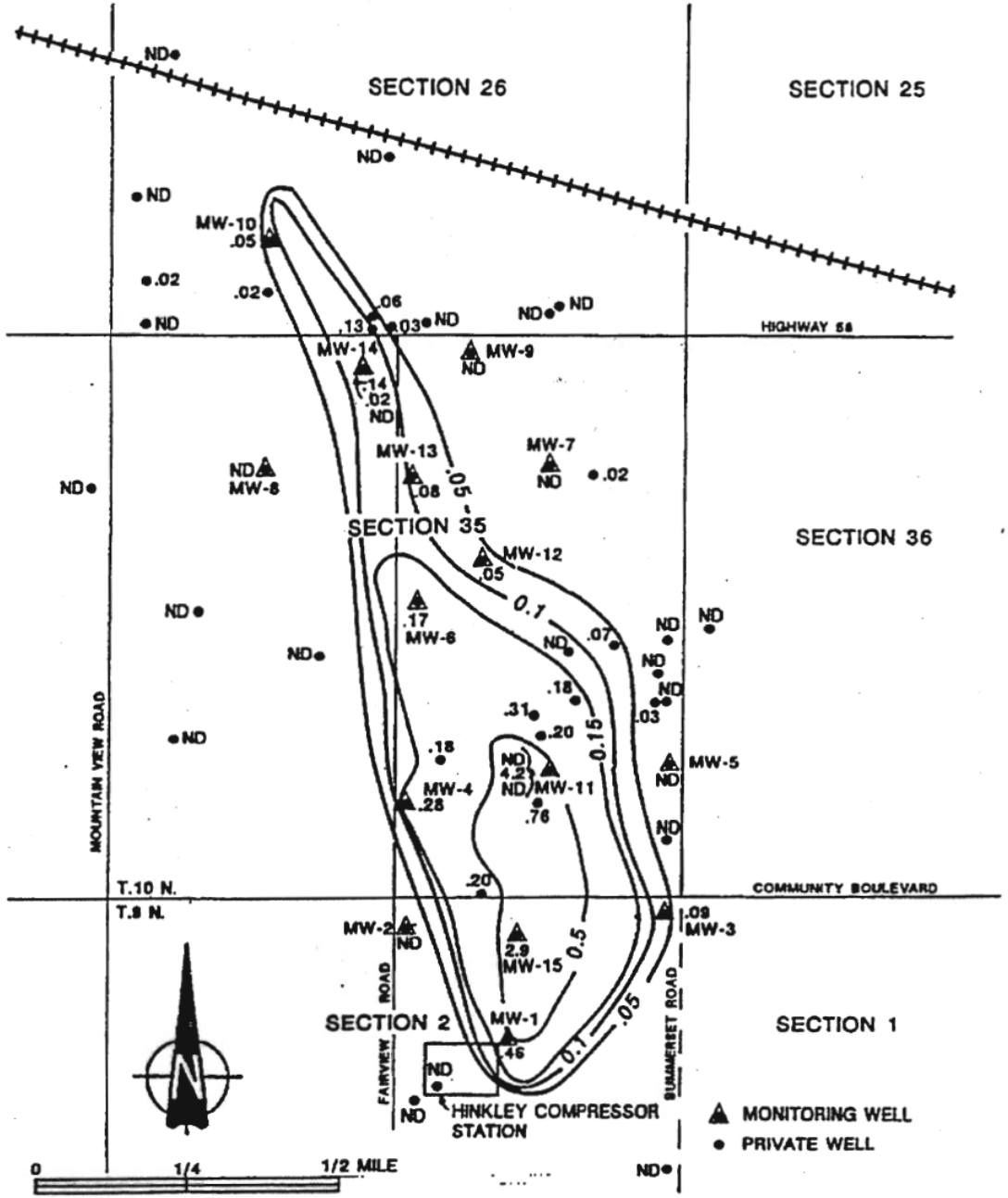
- California Public Health Goal and Action Level: 6 ppb
- 1,620+ wells sampled
- Sampling results
  - ND: 628
  - <4 ppb: 377
  - 4 to 6 ppb: 352
  - 6 to 10 ppb: 237
  - >10 ppb: 20



Santa Clara Valley Water District

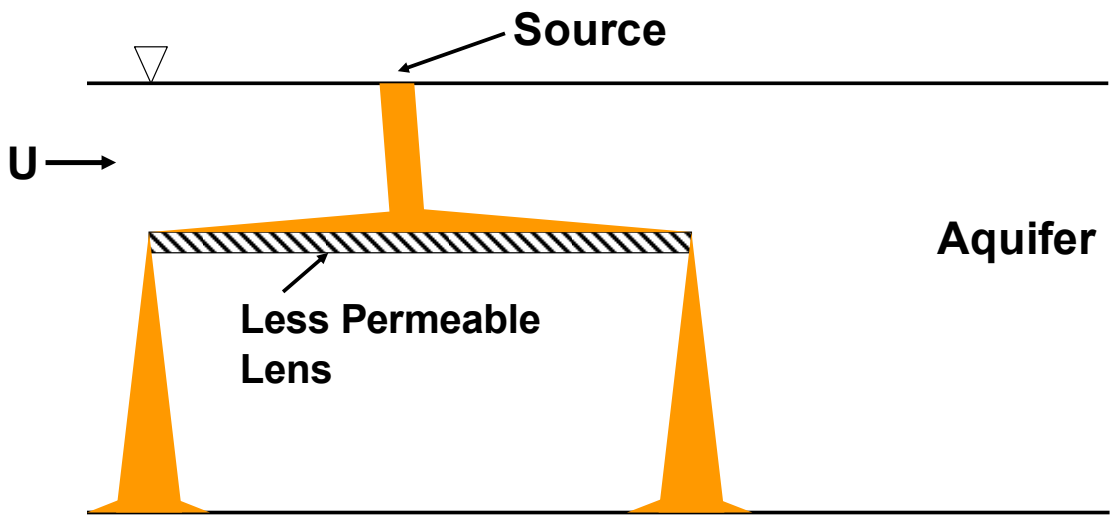
Example 2:

Hinkley, CA Natural Gas Compressor Station, Chromium Groundwater Plume, May 1988

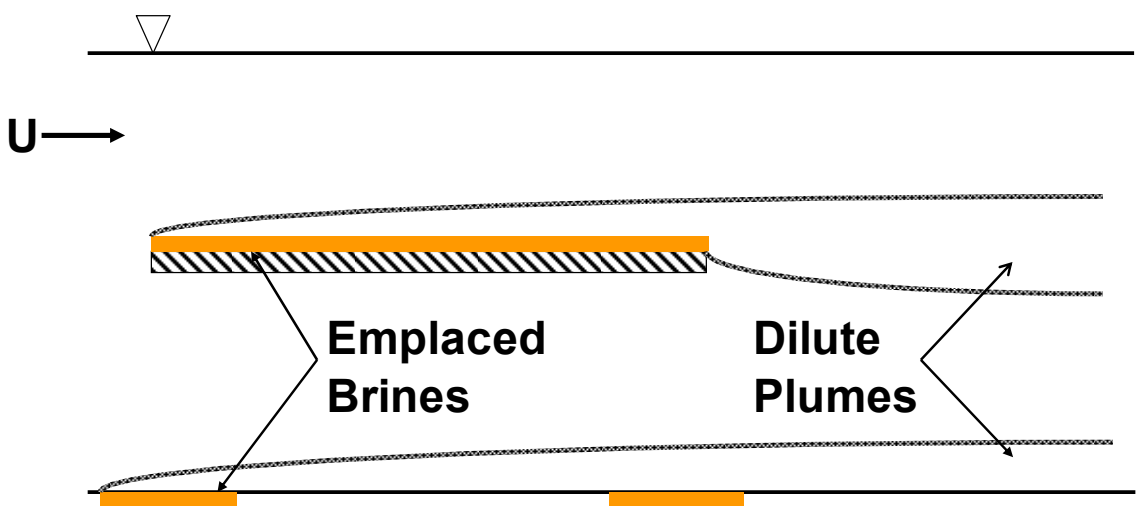


Ecology and Environment, Inc.

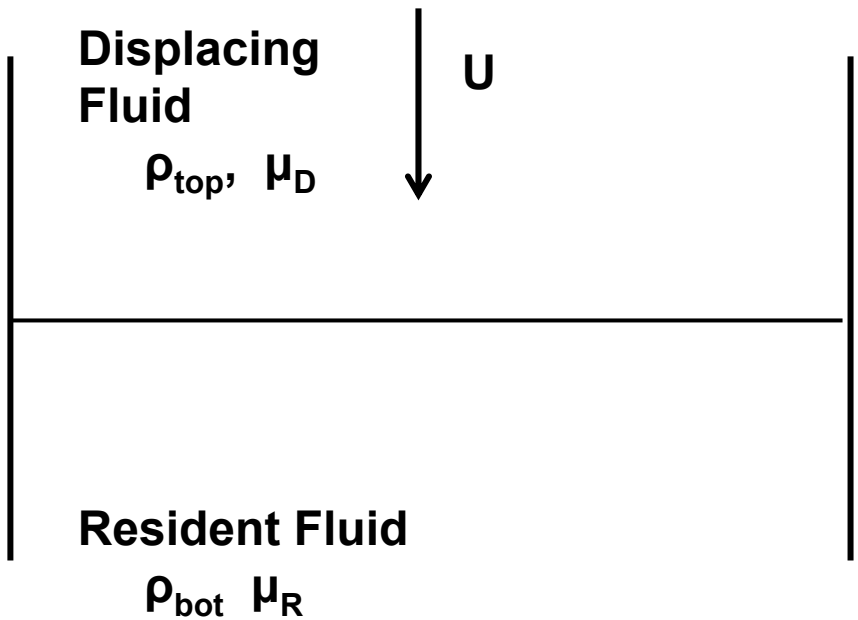
Brine Transport: Emplacement



Brine Transport: Release



Hill's 1952 Stability Analysis

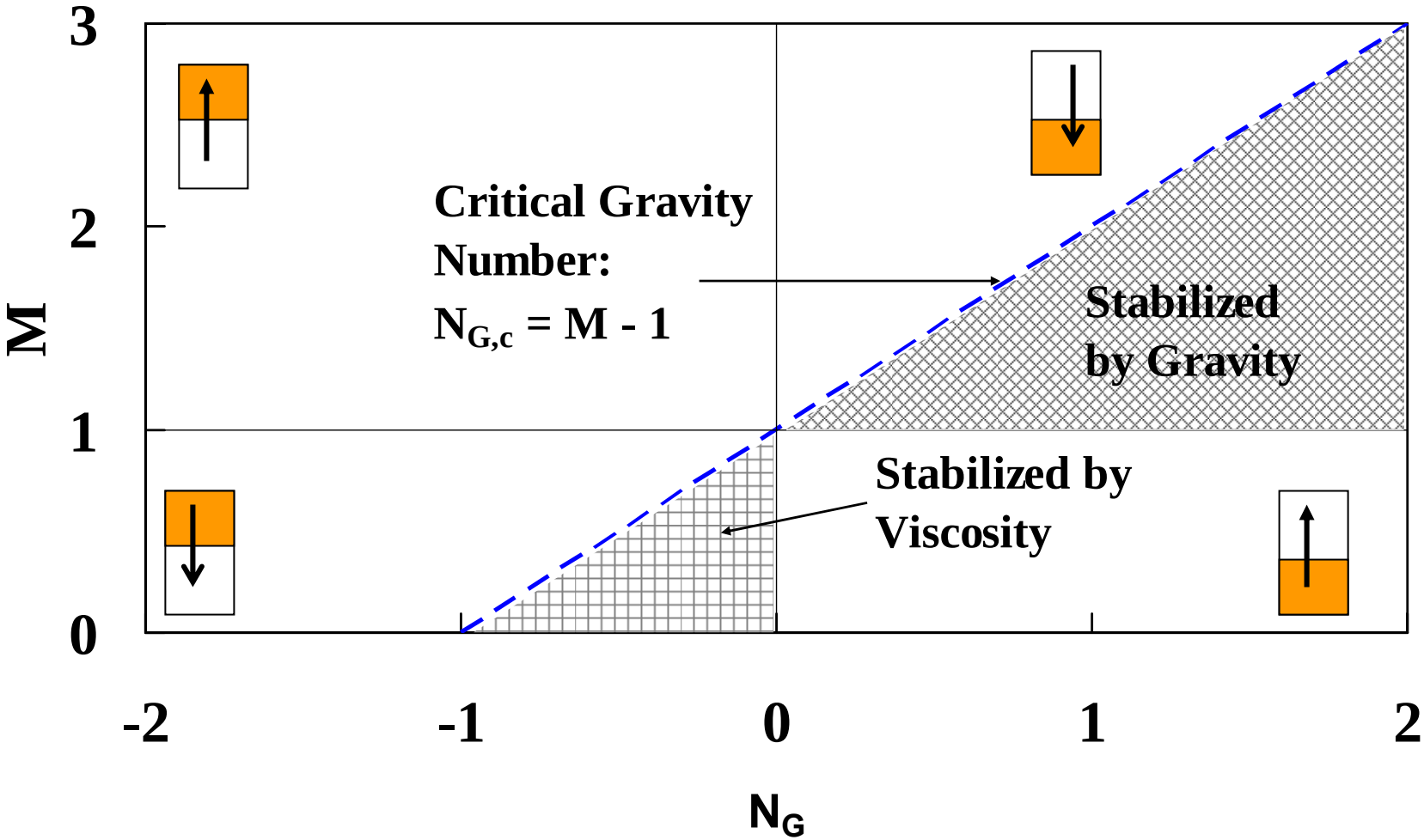


Criterion for Stable Displacement

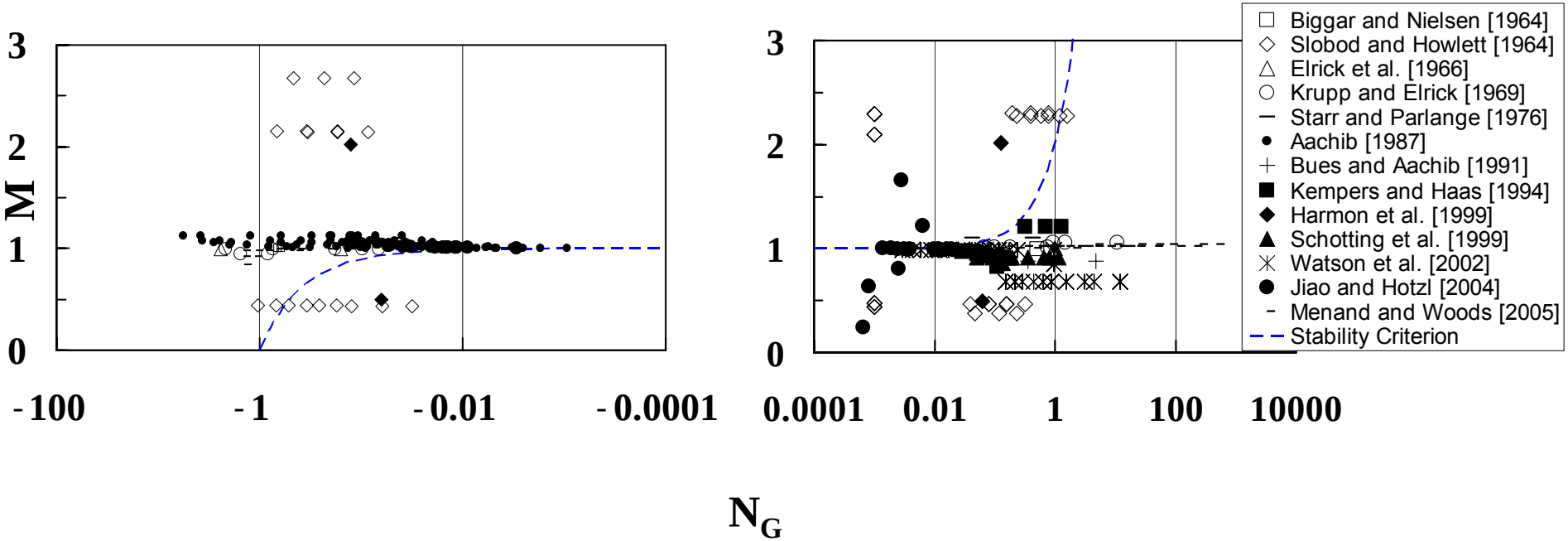
$$\frac{kg(\rho_{bot} - \rho_{top})}{n\,\mu_D\,|U|} > \frac{\mu_R}{\mu_D} - 1$$

$$N_G > M - 1$$

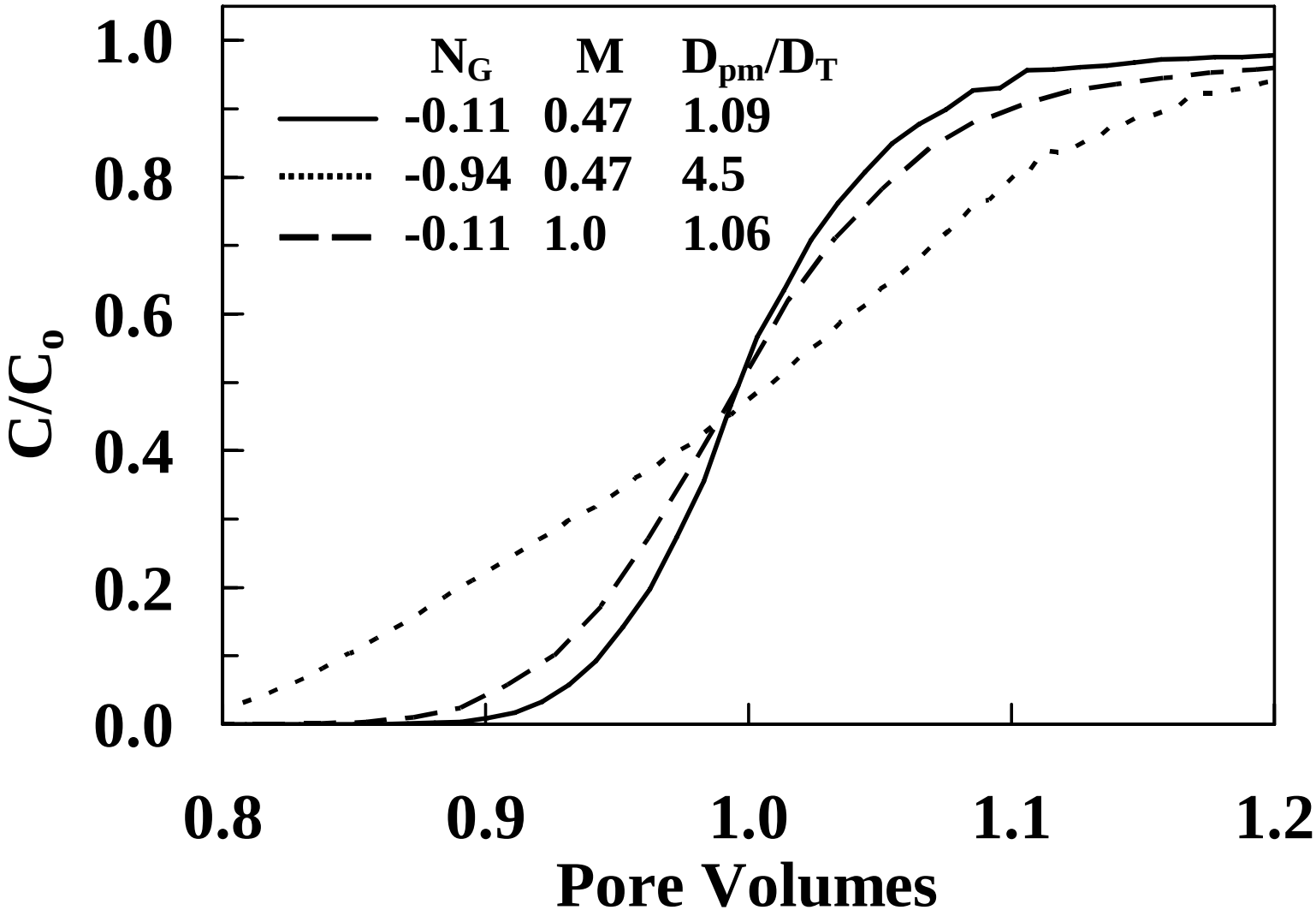
Hill's Stability Diagram for Brines



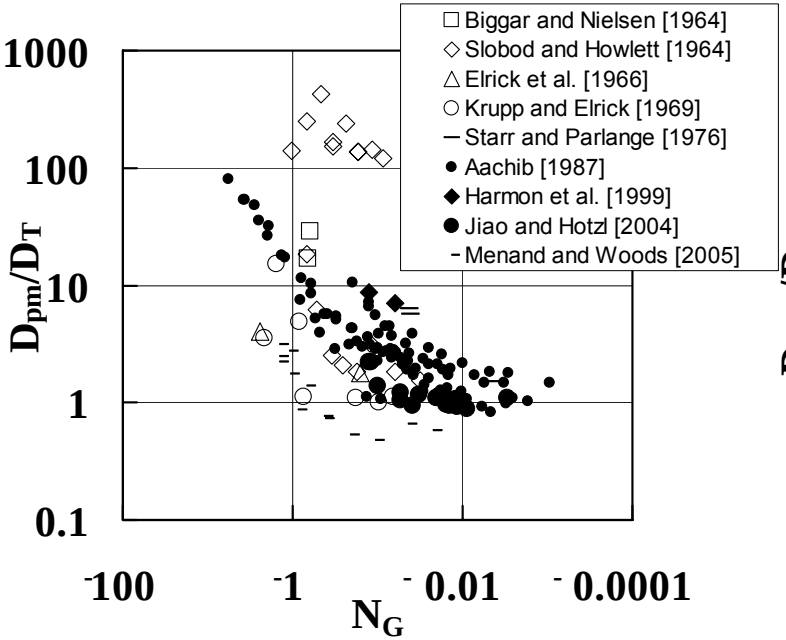
Experimental Data on 1-D Miscible Displacement

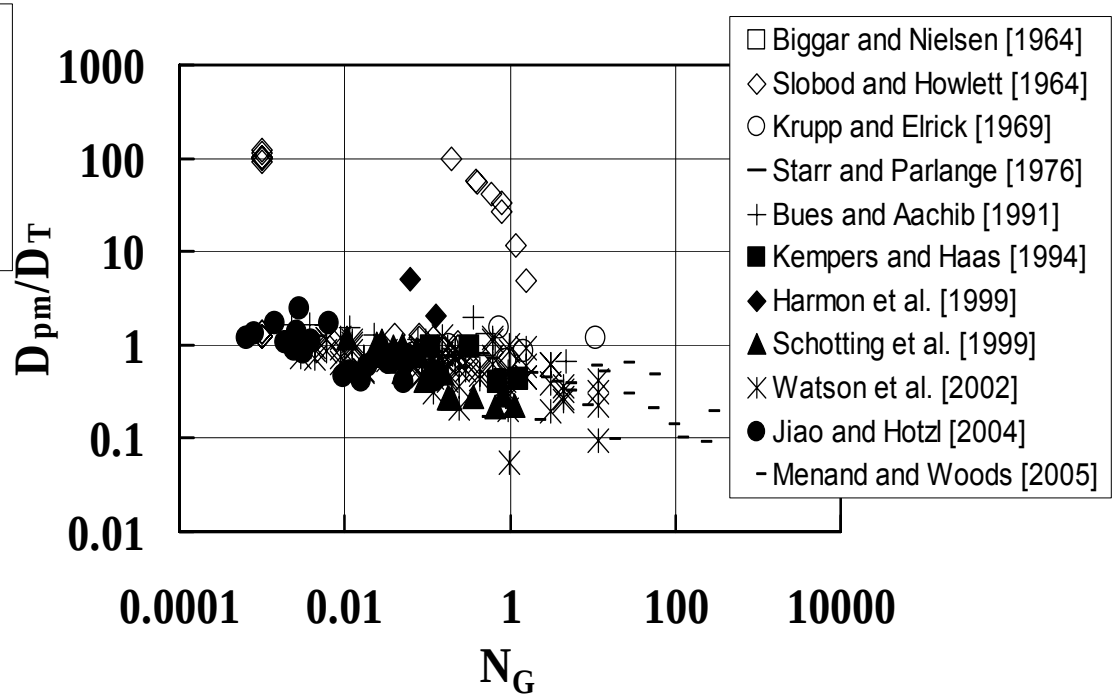


Example Breakthrough Curves (T. Flowers thesis)

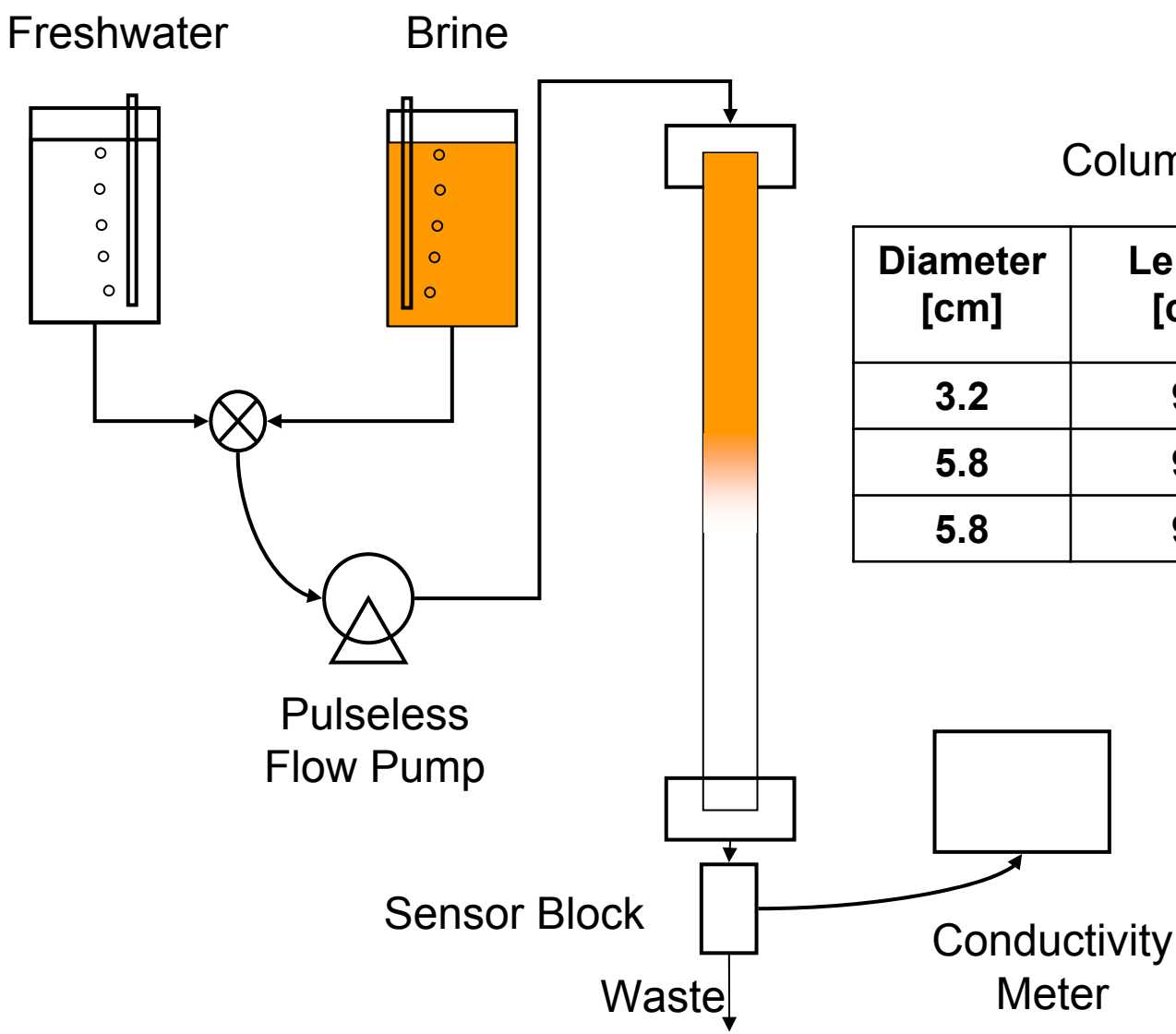


Normalized 1-D Dispersion from the Literature





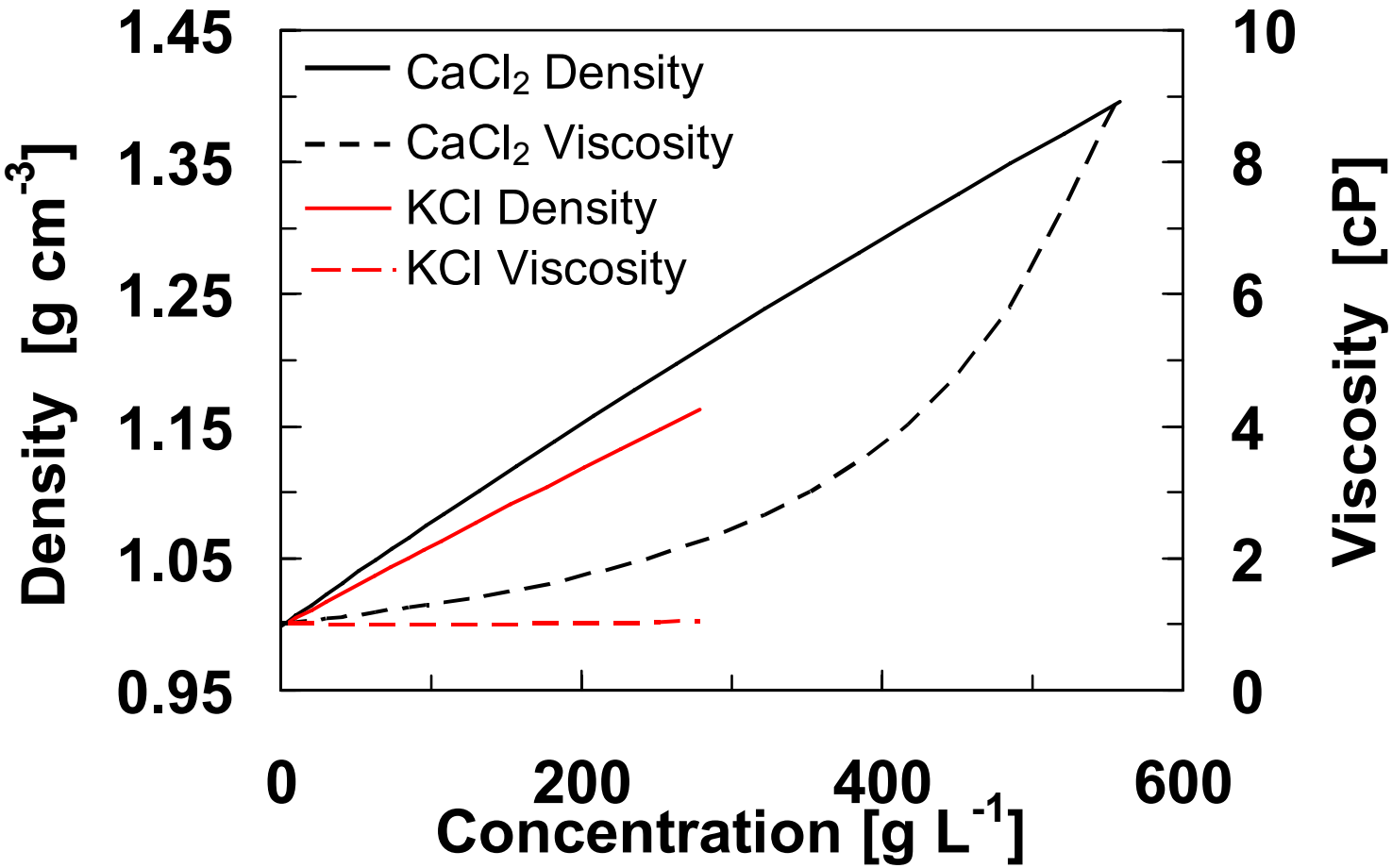
Experimental Program



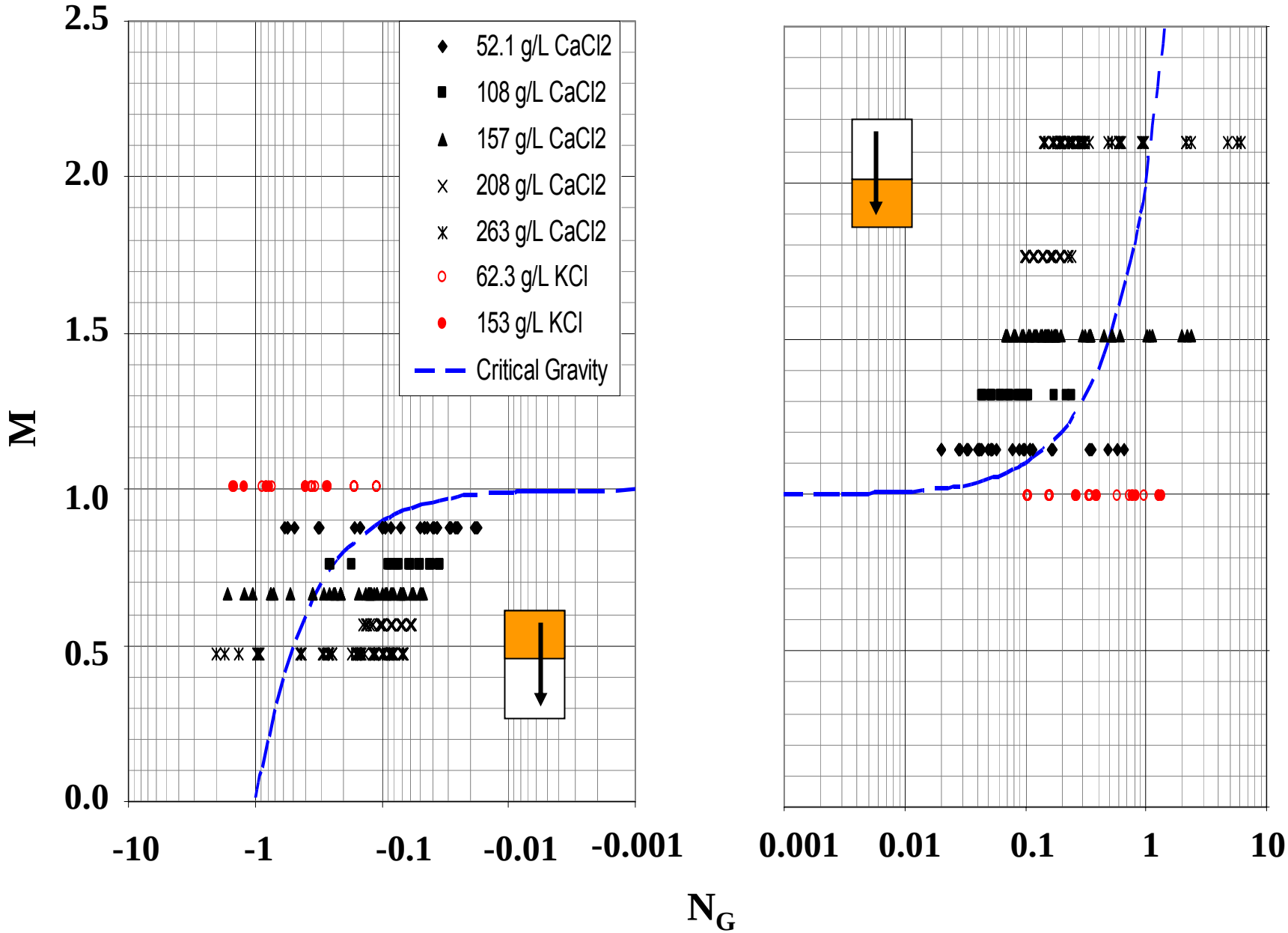
Column Properties

Diameter [cm]	Length [cm]	Permeability [10^{-8} cm^2]
3.2	97	93
5.8	98	92
5.8	96	353

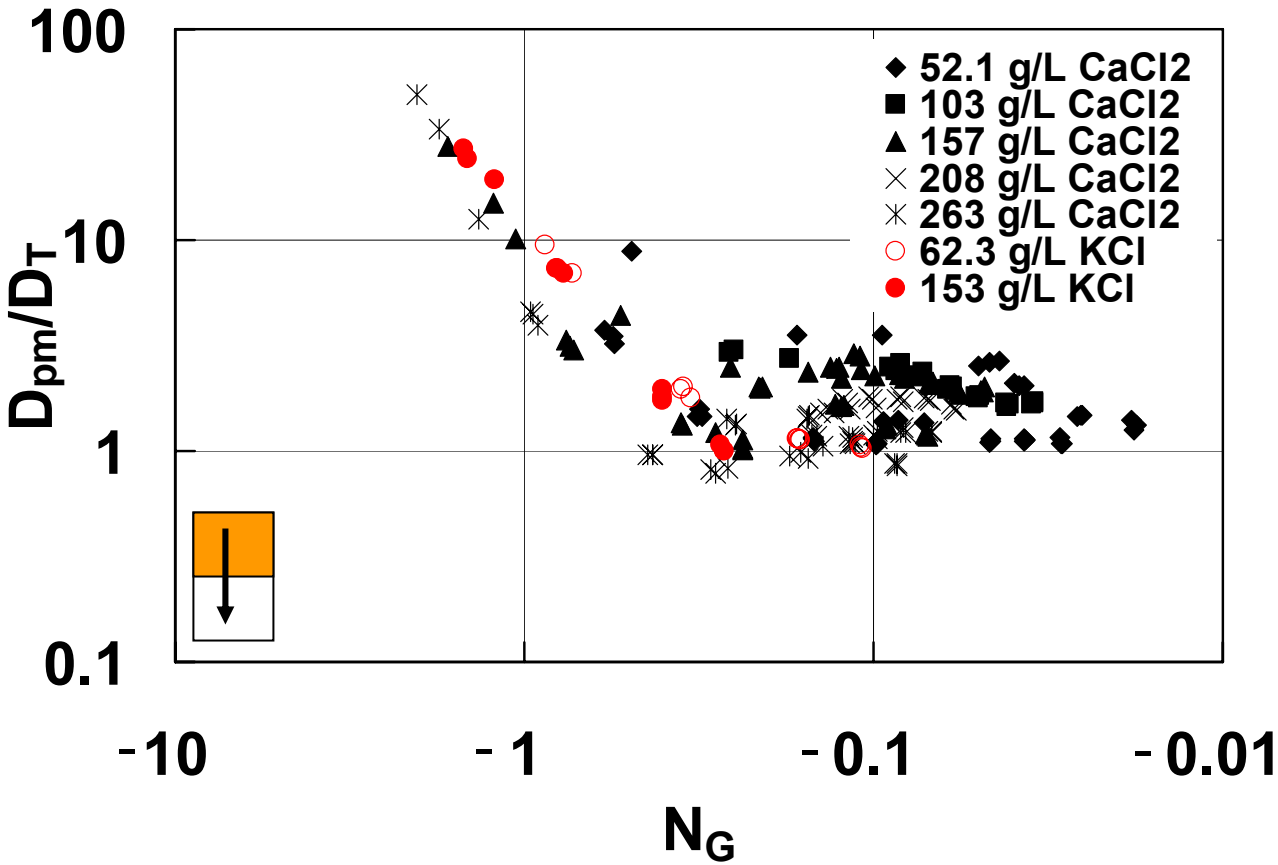
Experimental Brines



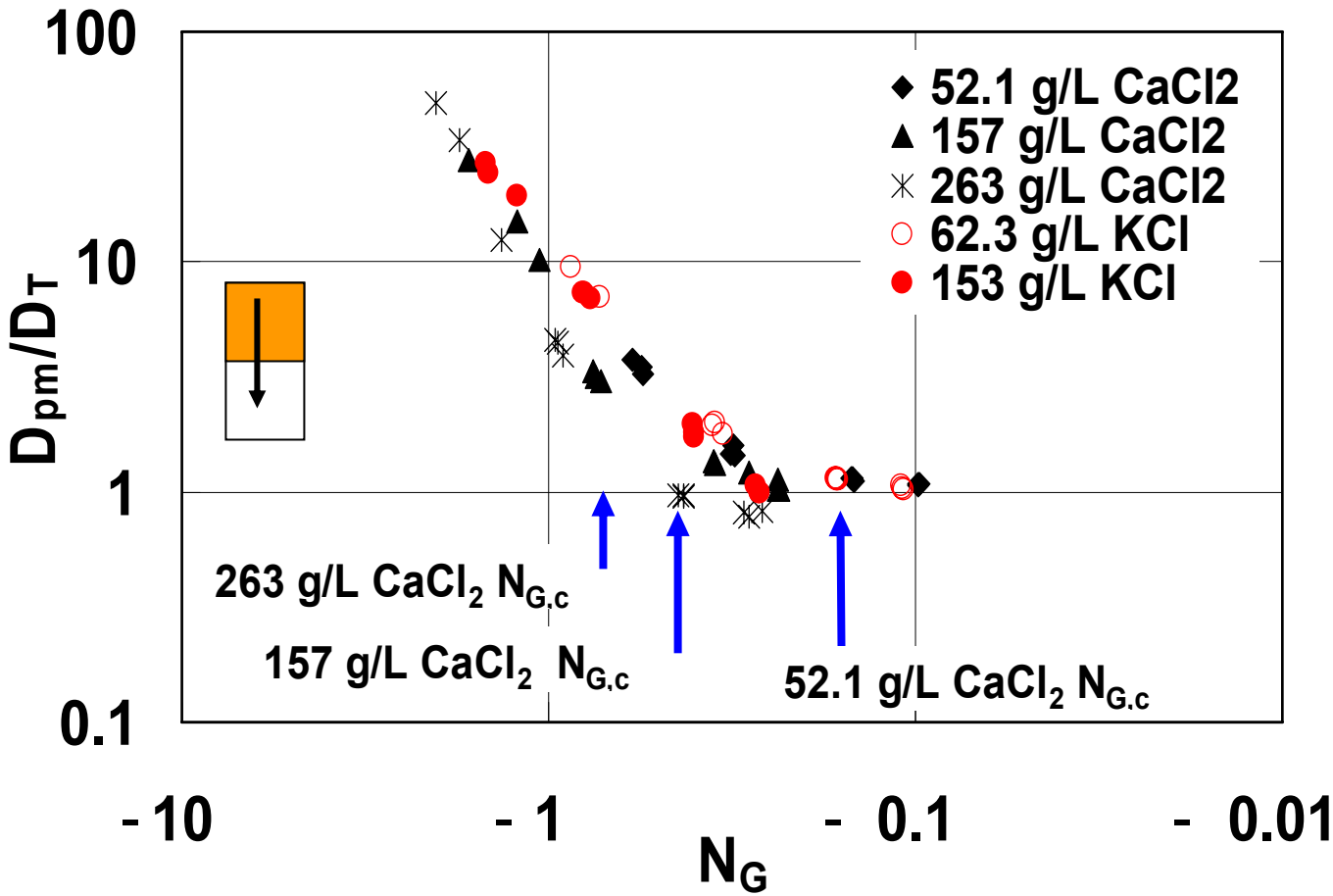
Experimental Conditions



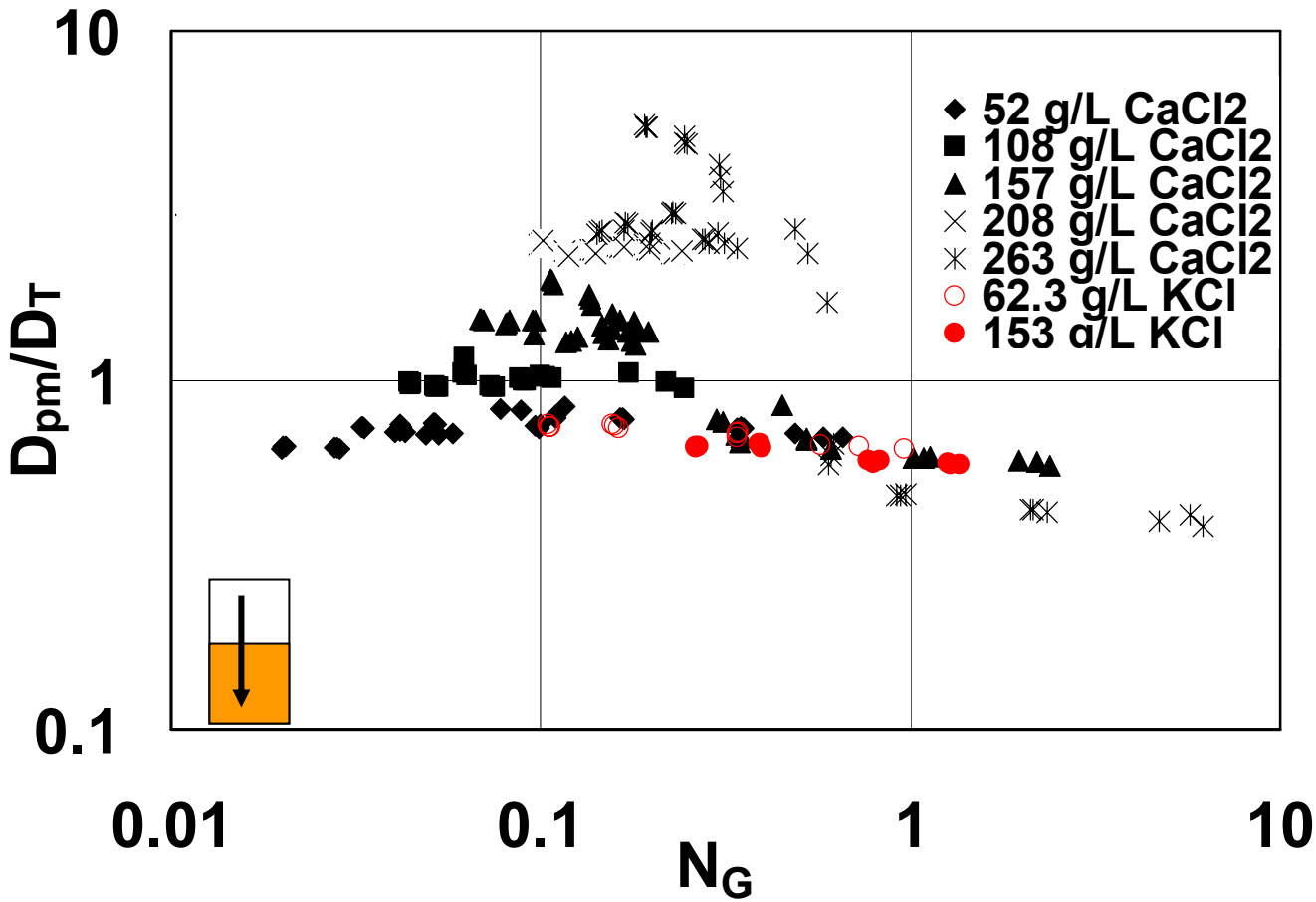
Experimental Results



Experimental Data, Higher Permeability Column

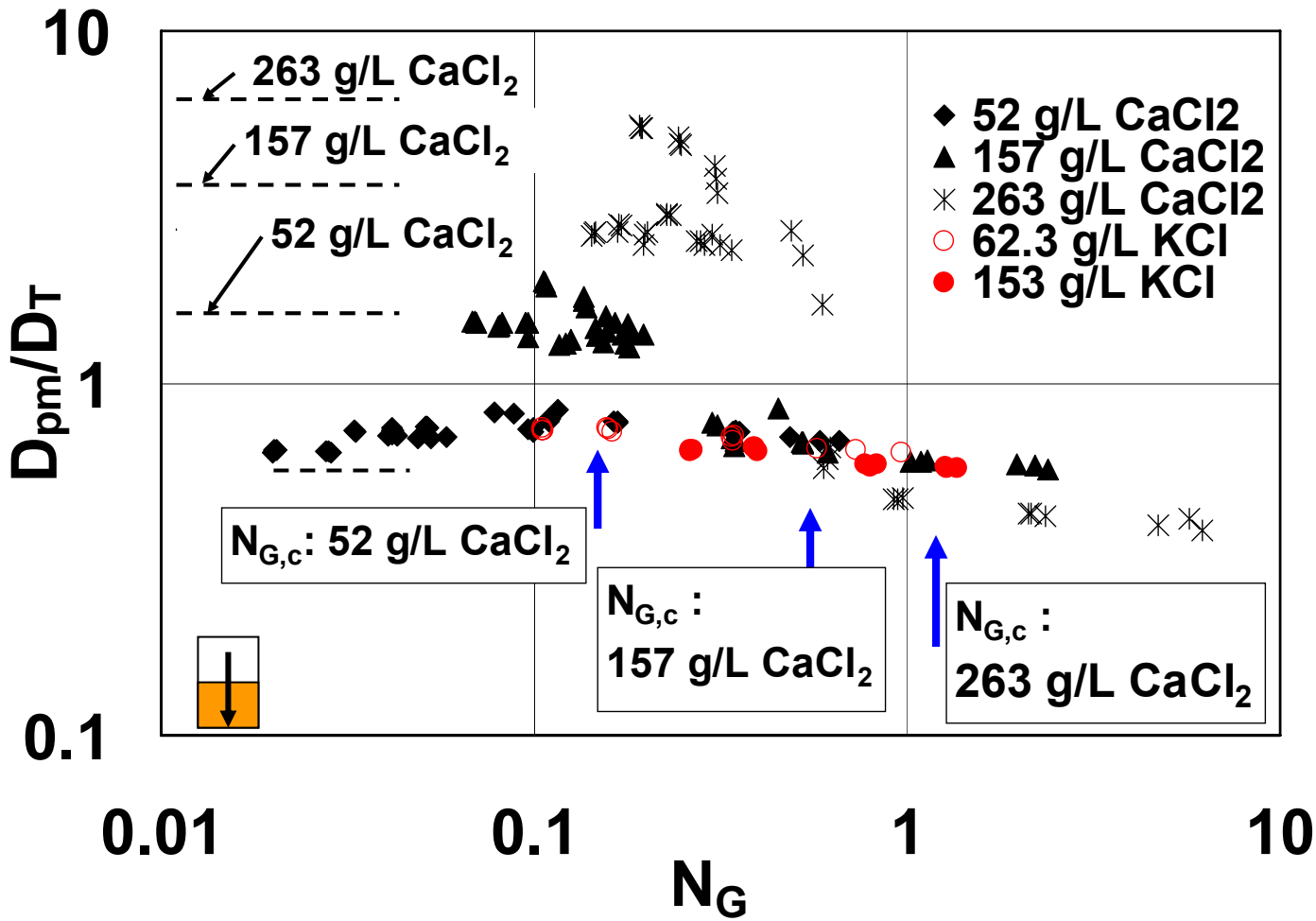


Experimental Data

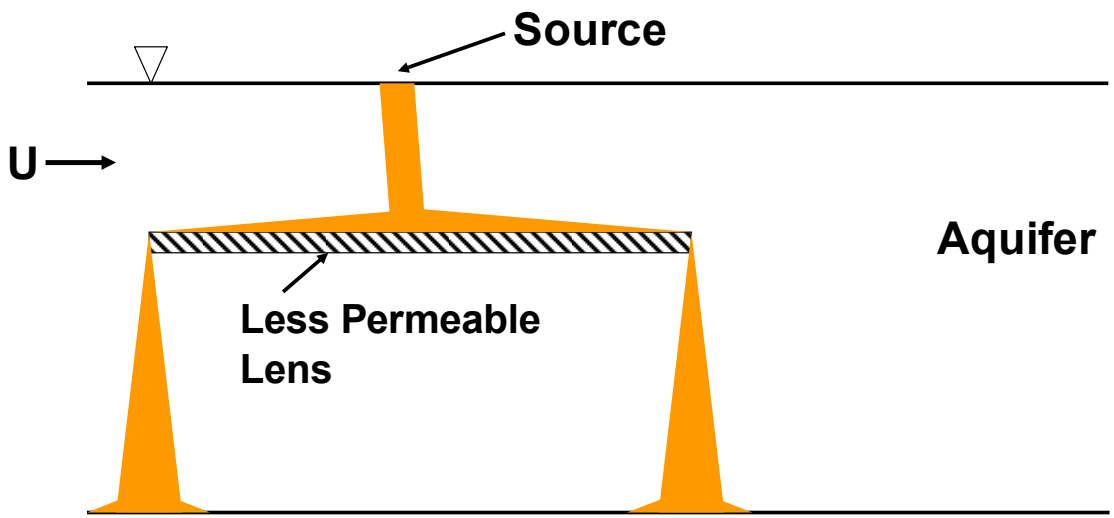


Selected Experimental Data

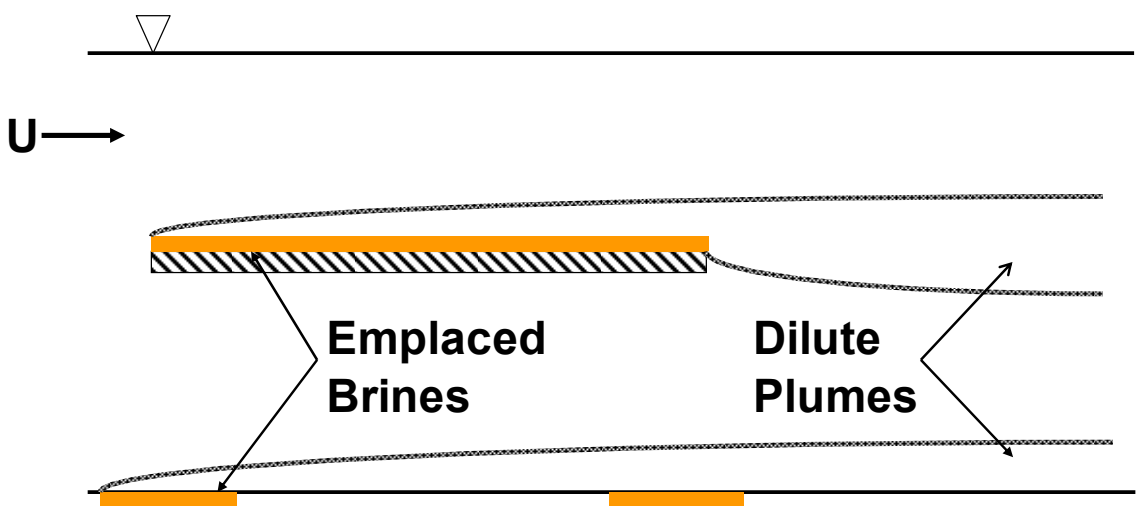
– – – – – Koval (1963) Asymptotic Prediction



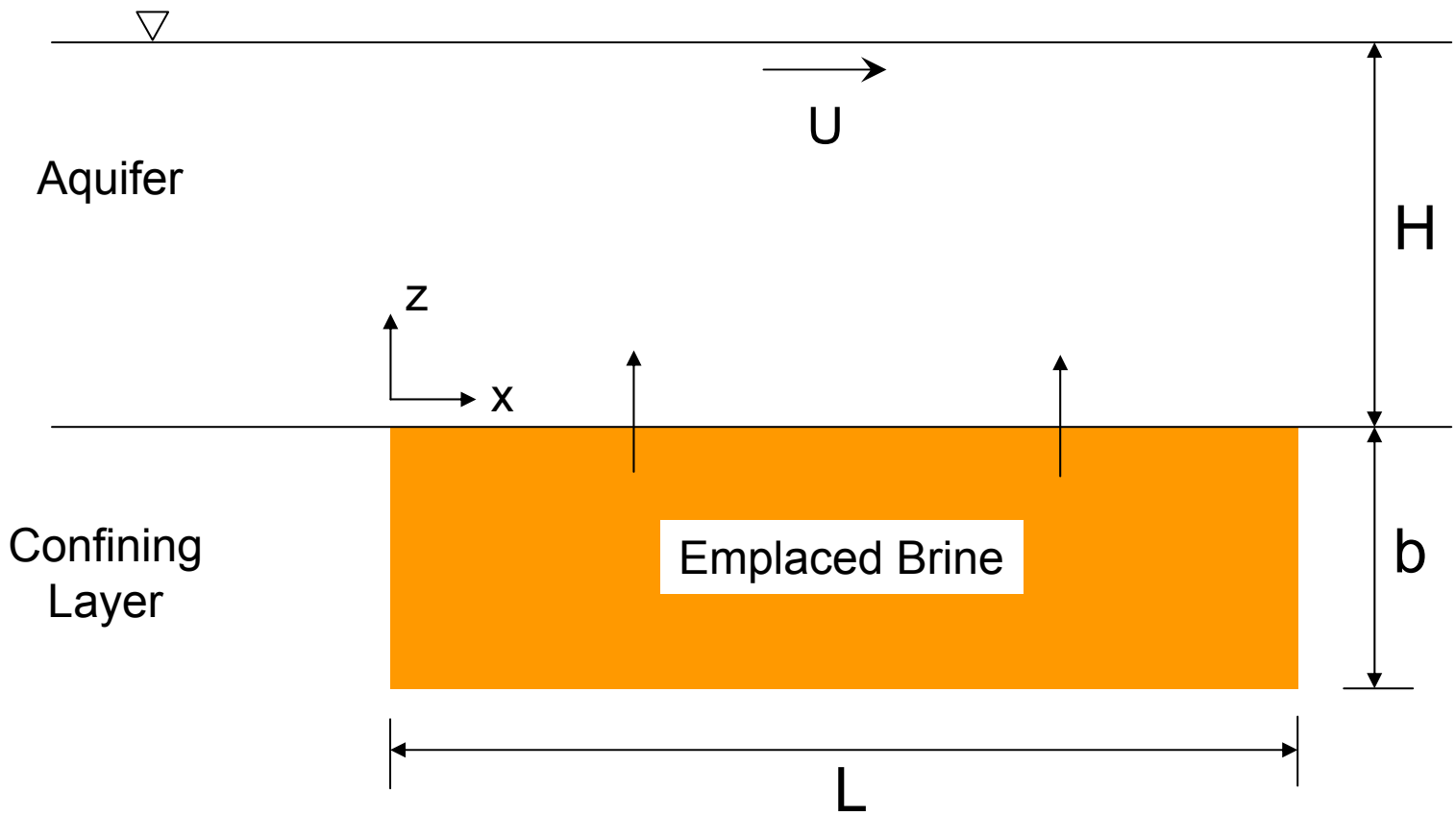
Brine Transport: Emplacement



Brine Transport: Release

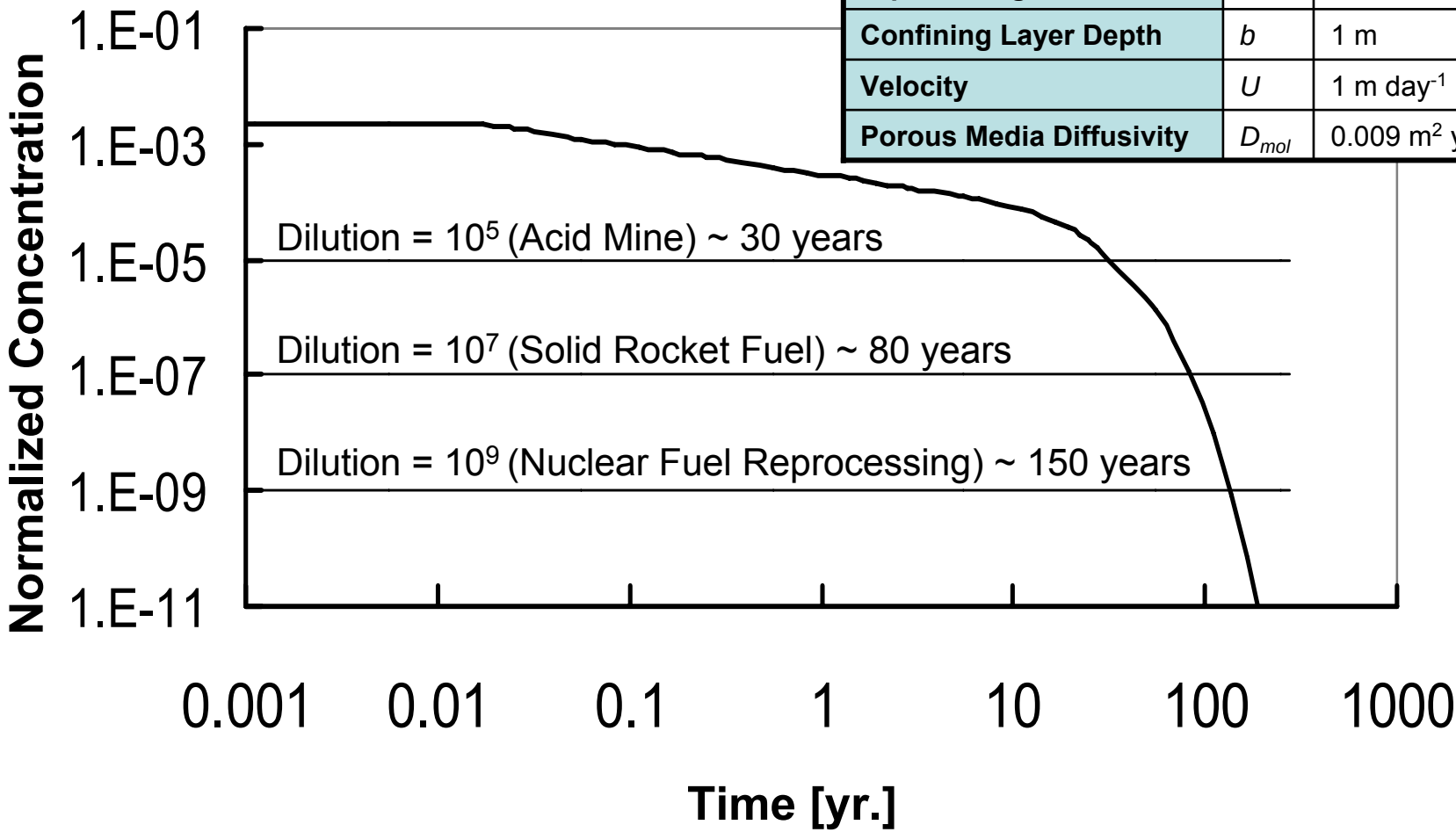


Geometry for Diffusion Controlled Release Model



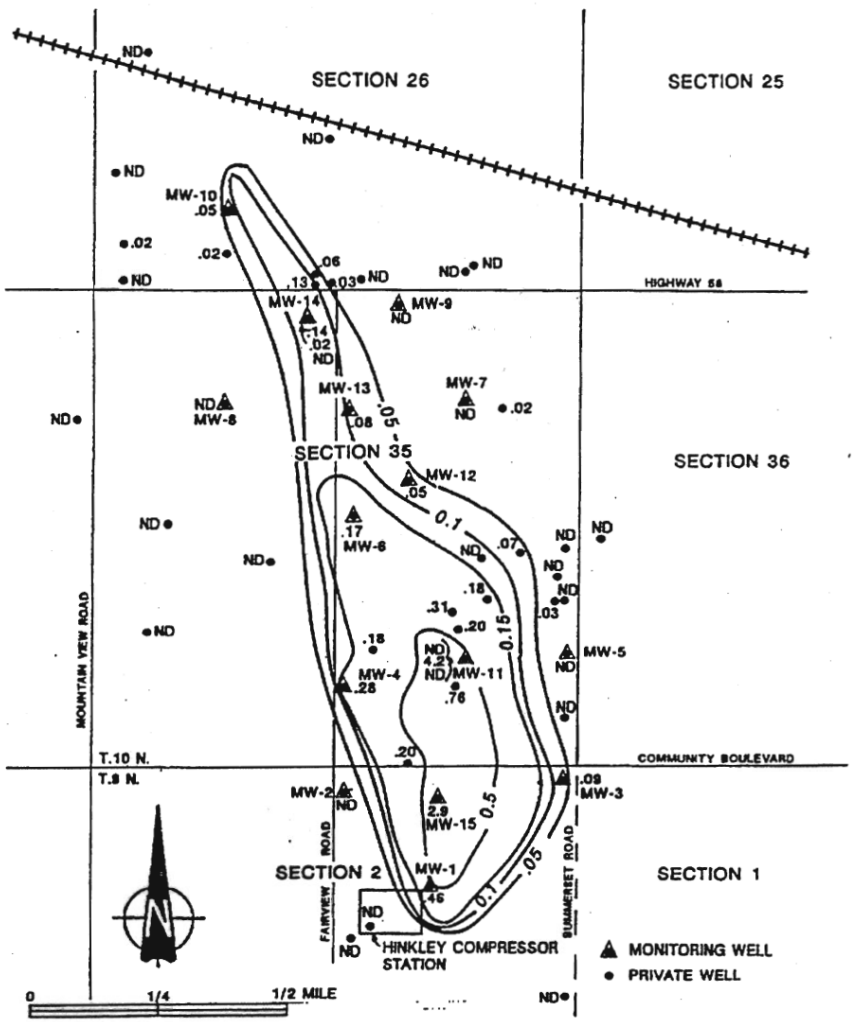
Predictions of Downstream Concentration

Spill Geometry		
Spill Length	L	20 m
Aquifer Height	H	5 m
Confining Layer Depth	b	1 m
Velocity	U	1 m day^{-1}
Porous Media Diffusivity	D_{mol}	0.009 m^2 yr^{-1}

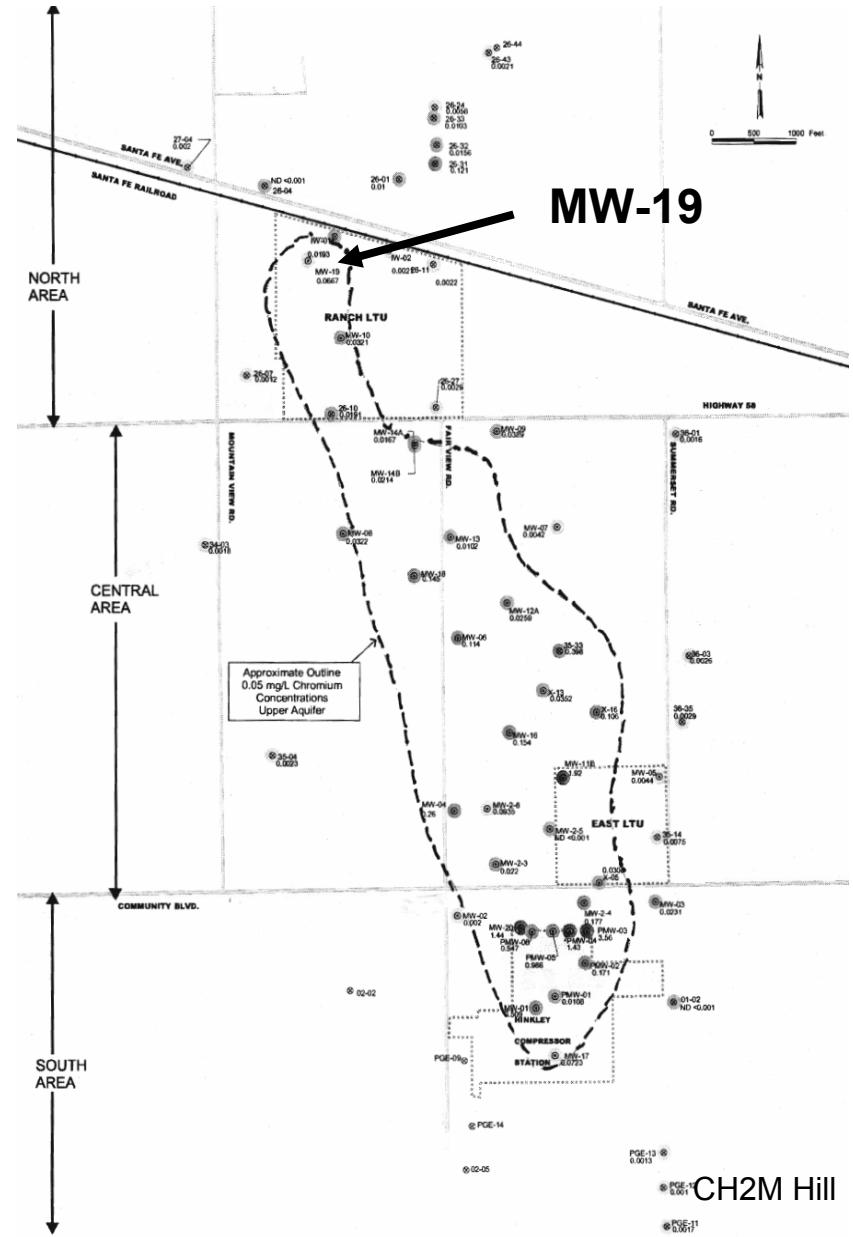


Hinkley Chromium Plumes

1988

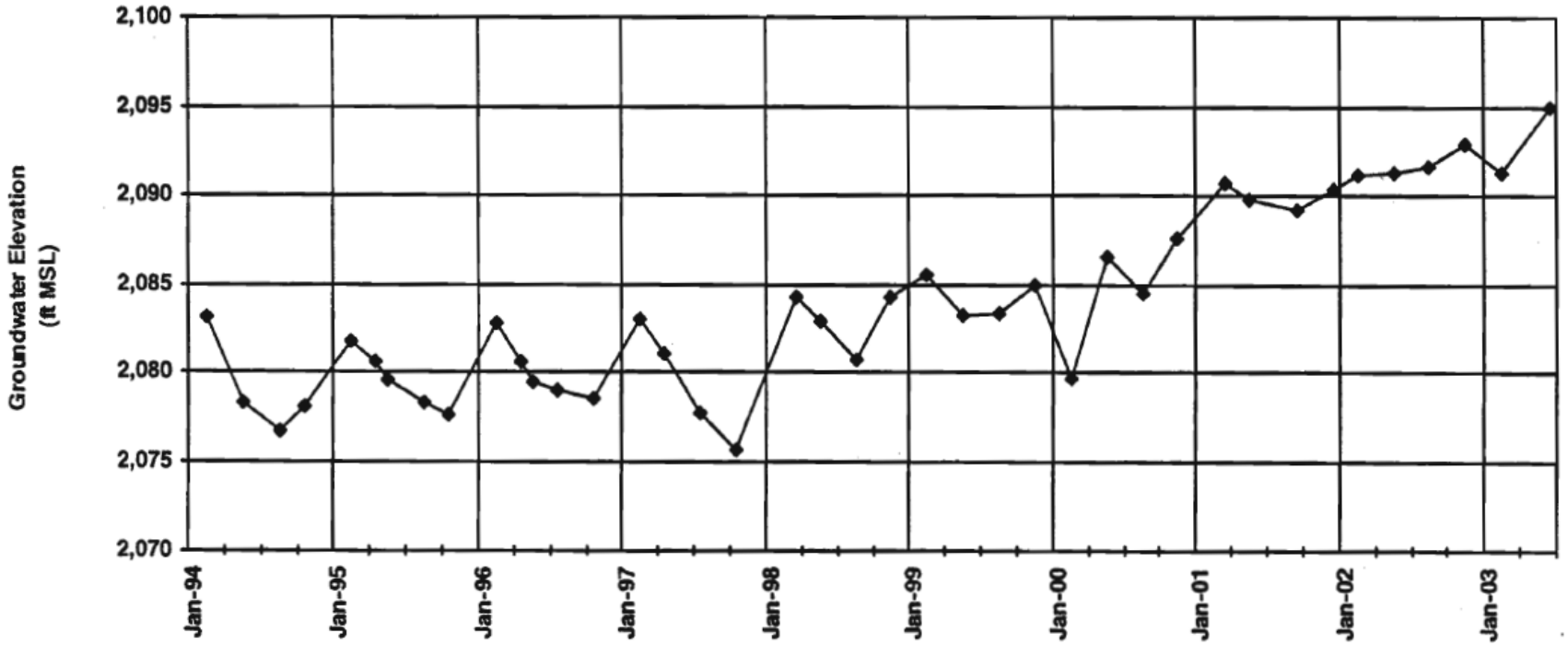


2002

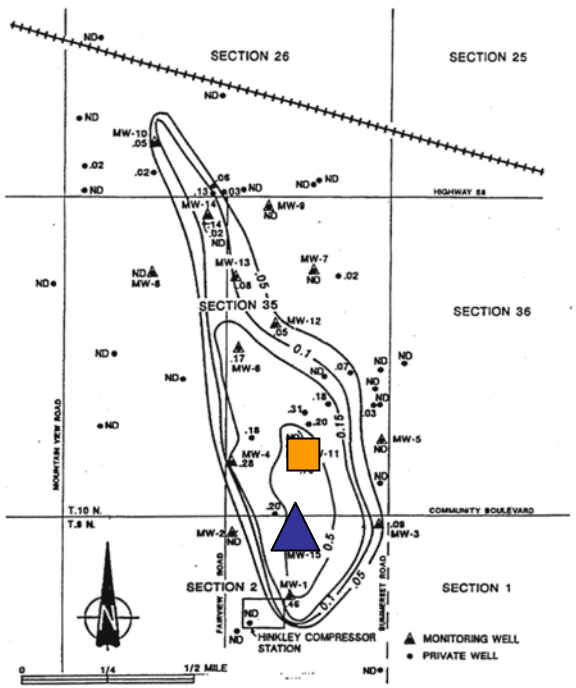


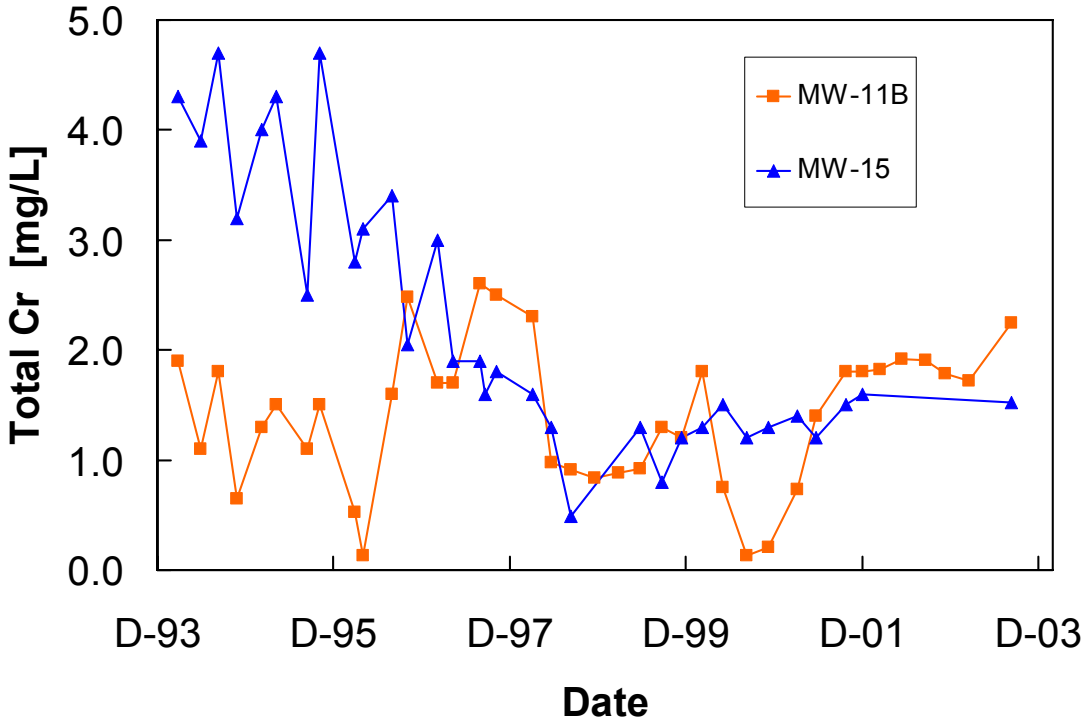
CH2M Hill

Groundwater Elevation at MW-19, Hinkley, CA



Chromium in Groundwater at Hinkley, CA





Summary

- Dense brines are released into the subsurface
- Brines sink
- Brines mix
- Contaminants within brines are released slowly into flowing groundwater
- Source identification and control are essential

References:

Flowers and Hunt (2000) Perchlorate in the Environment, E. T. Urbansky, ed.

Flowers and Hunt (2007) Water Resources Research