Selection of an Optimal Site-Specific Method for the Measurement of LNAPL Transmissivity

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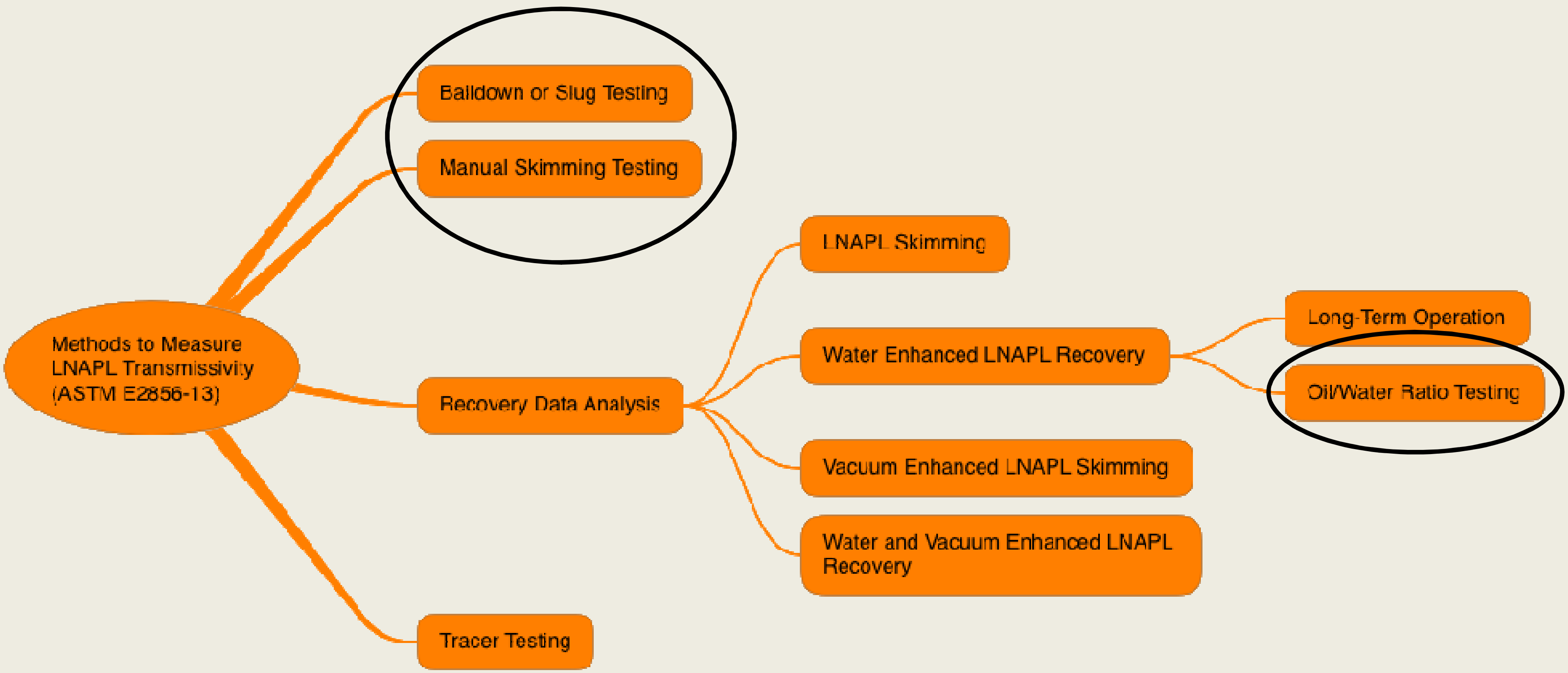
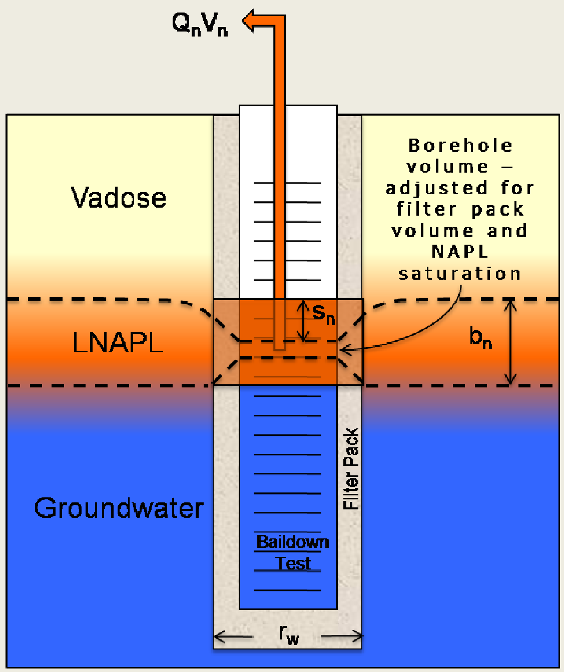
Three Short Term LNAPL Transmissivity Measurement Methods are Available in ASTM E2856 Guidance for the Measurement of LNAPL Transmissivity



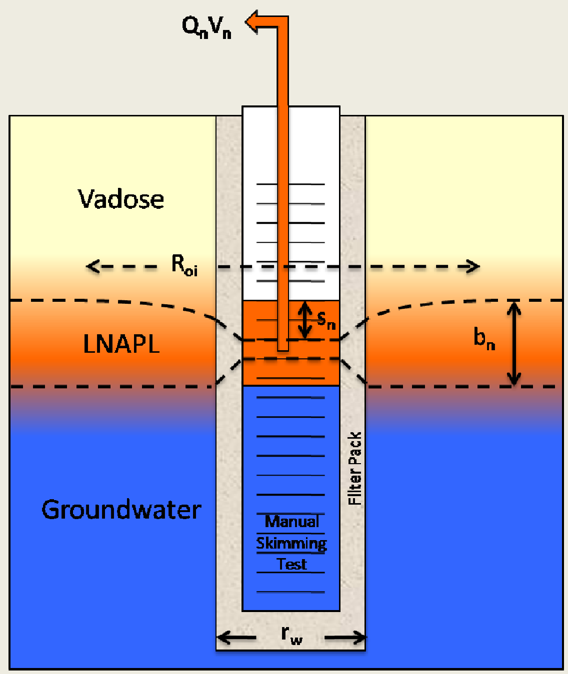
Hawthorne, J. Michael (2013) *LNAPL Transmissivity from Total Fluids Recovery Data, Part 1: Calculation Methodology*, Applied NAPL Science Review, vol. 3, issue 2, February 2013

What are baildown testing, manual skimming testing, and oil/water ratio testing?

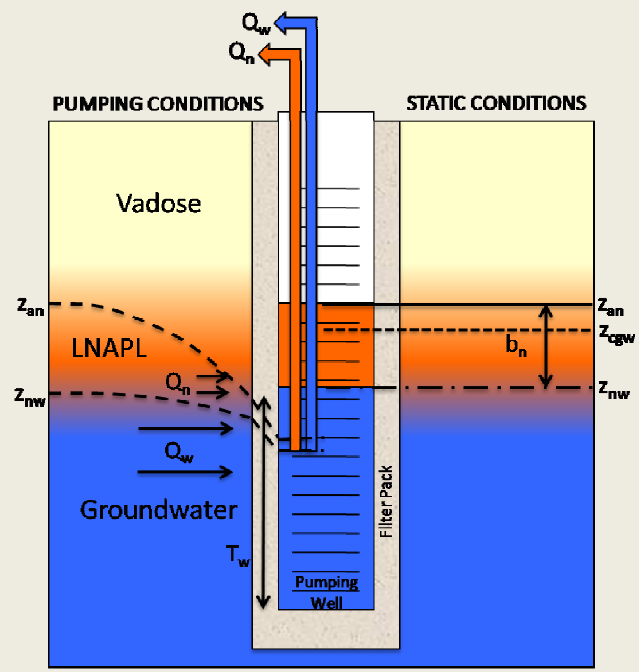
Baildown/Slug Test



Manual Skimming Test

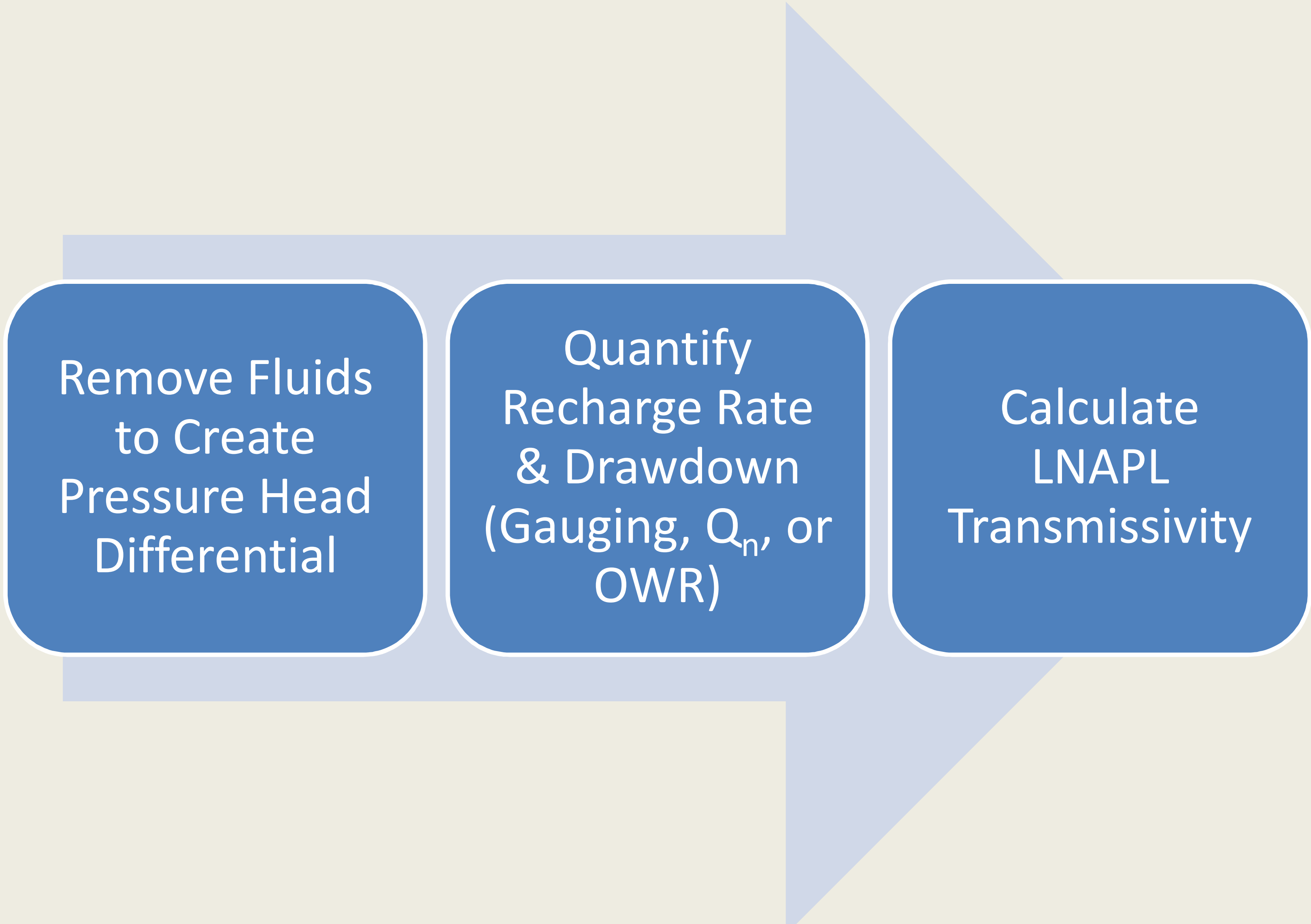


Oil/Water Ratio Test

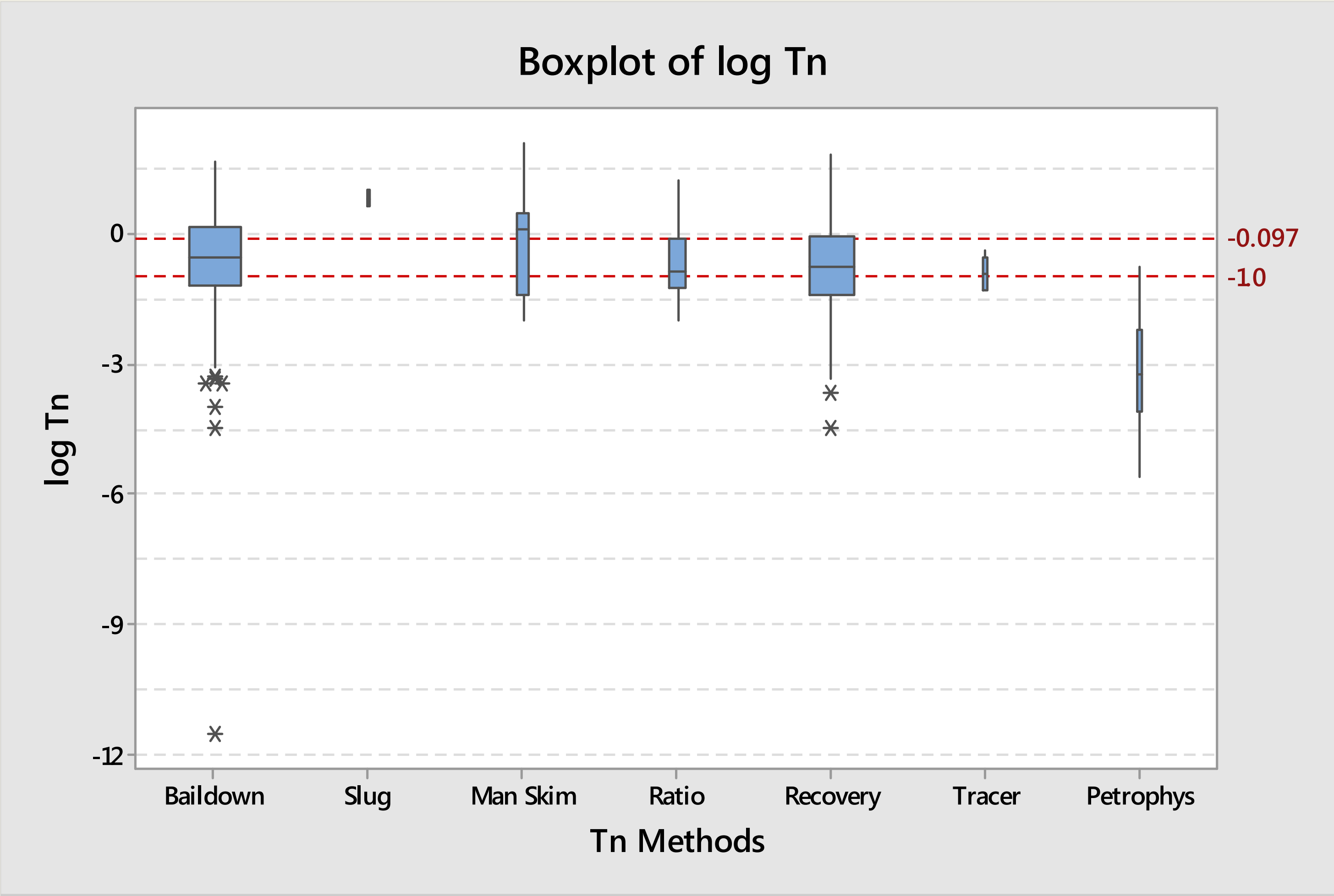


Hawthorne, J. Michael (2010) *LNAPL Transmissivity (T_n): Remediation Design, Progress and Endpoints*, Texas Commission on Environmental Quality Annual Trade Fair and Conference, May 2010

Generalized LNAPL Transmissivity Testing Dynamics



A recent API nationwide statistical analysis of LNAPL transmissivity found that all methods except petrophysical calculation appear to generate similar (repeatable) values (insufficient data for slug testing)



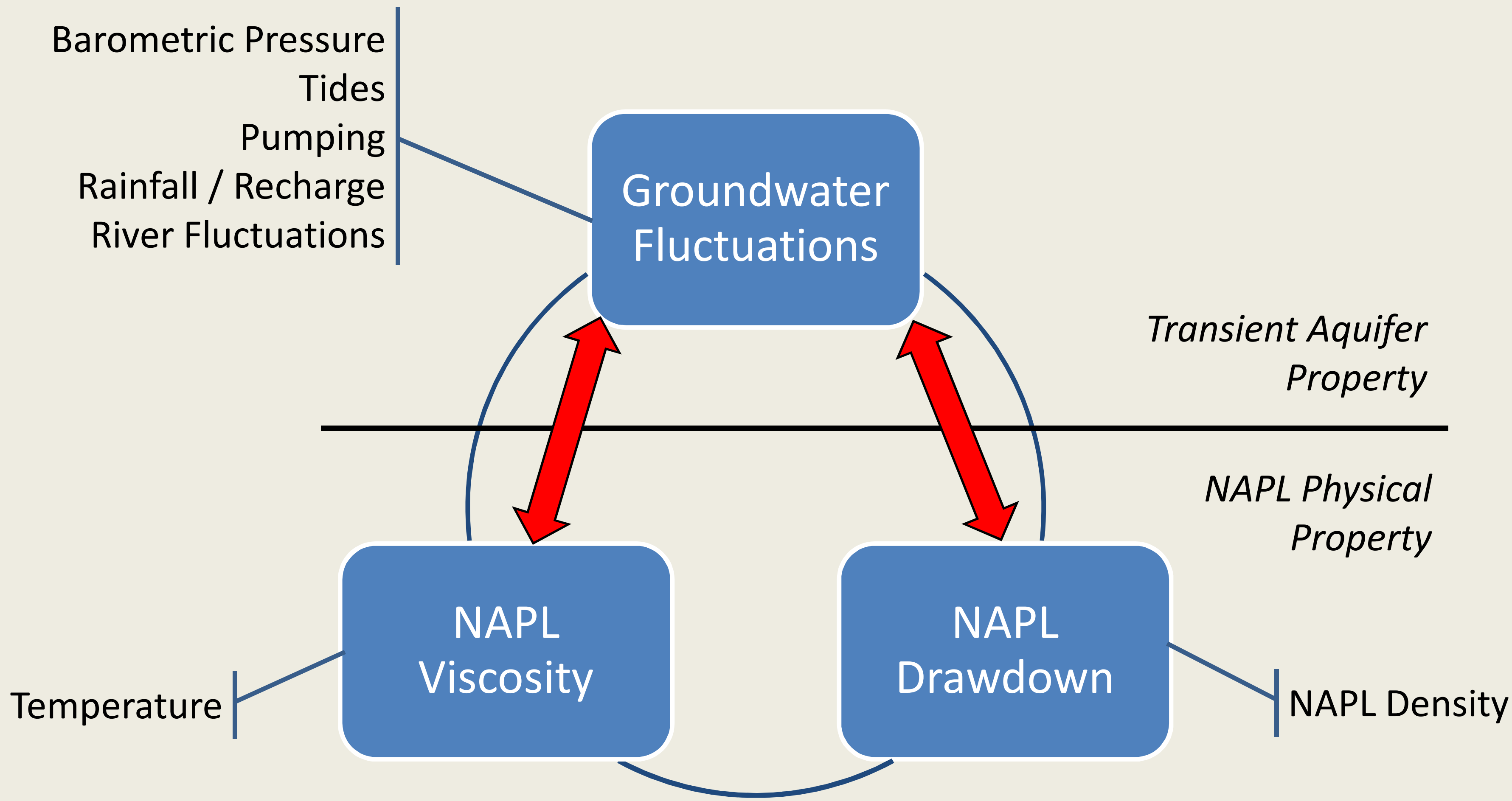
Hawthorne, J. Michael, Dennis Helsel and Charles Stone (2015) *Nationwide Statistical Analysis of LNAPL Transmissivity*, unpublished research conducted by H_2A Environmental, Ltd. on behalf of The American Petroleum Institute

ASTM E2856-13 guidance for T_n test method selection, modified

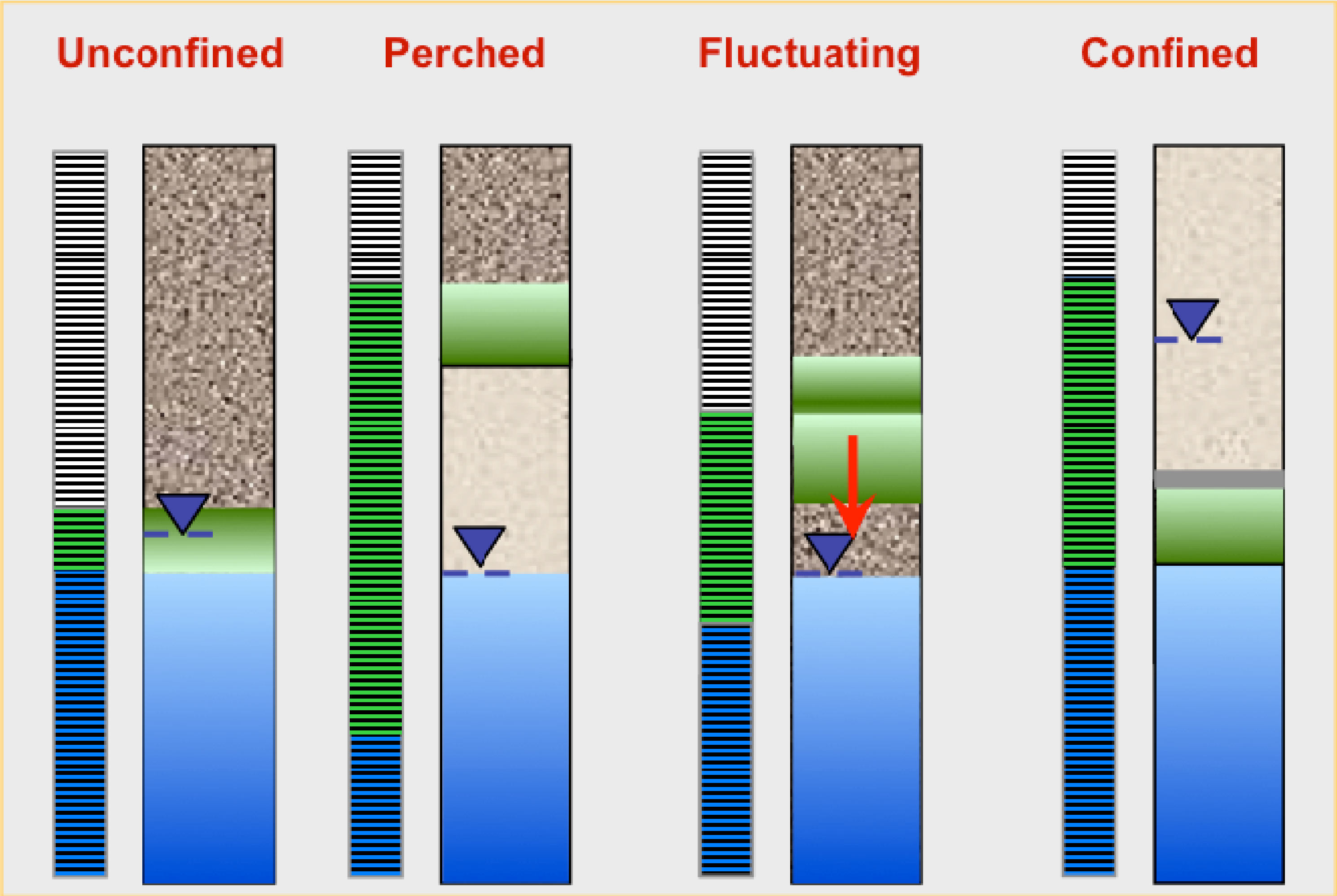
Factor	Baildown (BD) Test	Manual Skimming (MS)	Oil/Water Ratio (OWR)
Waste Disposal	Minimal	Moderate	Large
Aquifer Extent	Small	Moderate	Moderate – Large
Capital Cost	Low	Low – Moderate	Moderate
Test Duration	Minutes – Months	Minutes – Days/Weeks	Minutes – Hours
SC1:	s_n sensitive	s_n sensitive	Can be s_n insensitive
SC2:	Equilibrium required	Equilibrium required	Equilibrium optional
SC3:	Recommend ANT>0.5 foot; Require ANT>0.2 foot	Works with any measurable ANT	Works with any measurable ANT
SC4:	Any hydrogeologic condition	Any hydrogeologic condition	Any hydrogeologic condition (Adjust calc for perched)
Power (air, electricity, etc.)	Useful but not necessary	Preferred but not necessary	Required

See ASTM E2856-13 for a more detailed discussion

Critical variables I'll focus on today in the selection of an optimal site-specific test methodology for LNAPL transmissivity



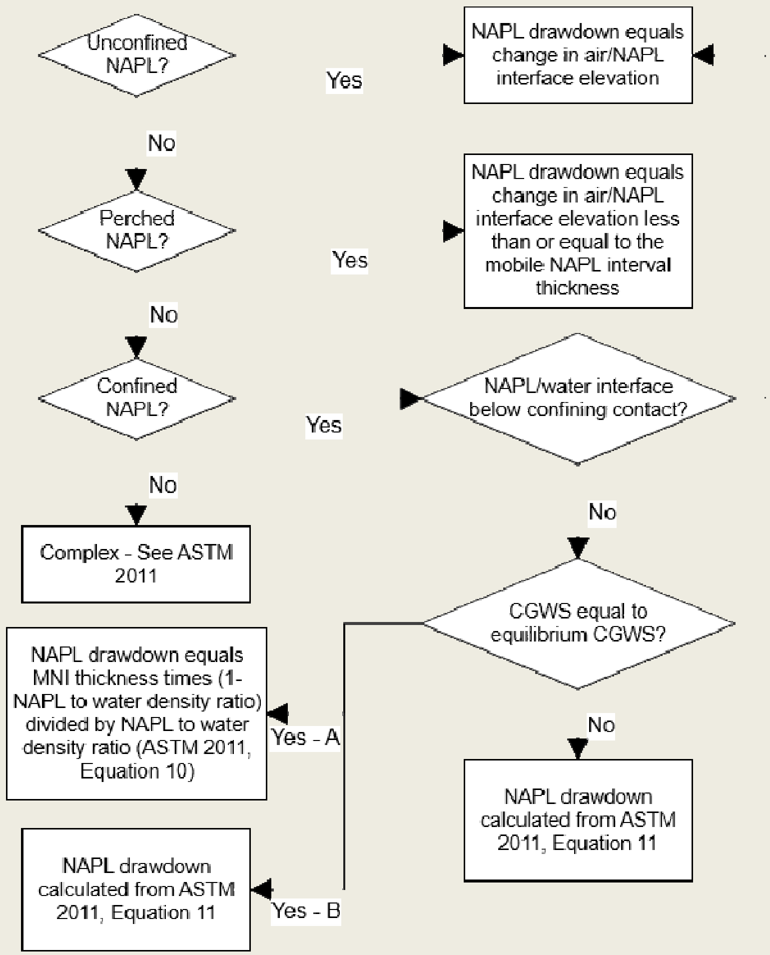
The NAPL hydrogeologic condition can strongly affect the ANT in the well, requiring correction to determine the MNI

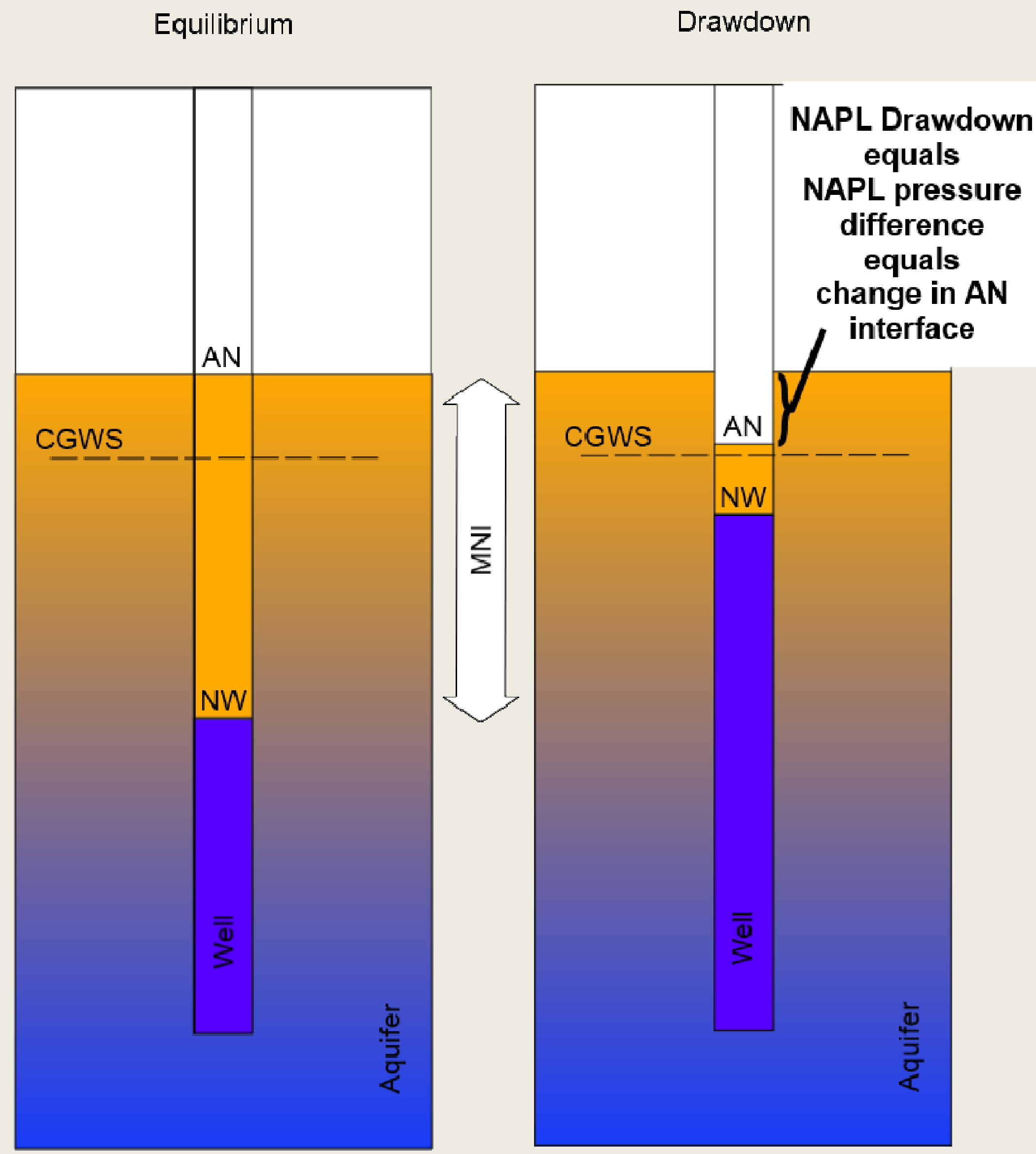


Modified after Kirkman (2009)

What is NAPL Drawdown?

Unconfined NAPL

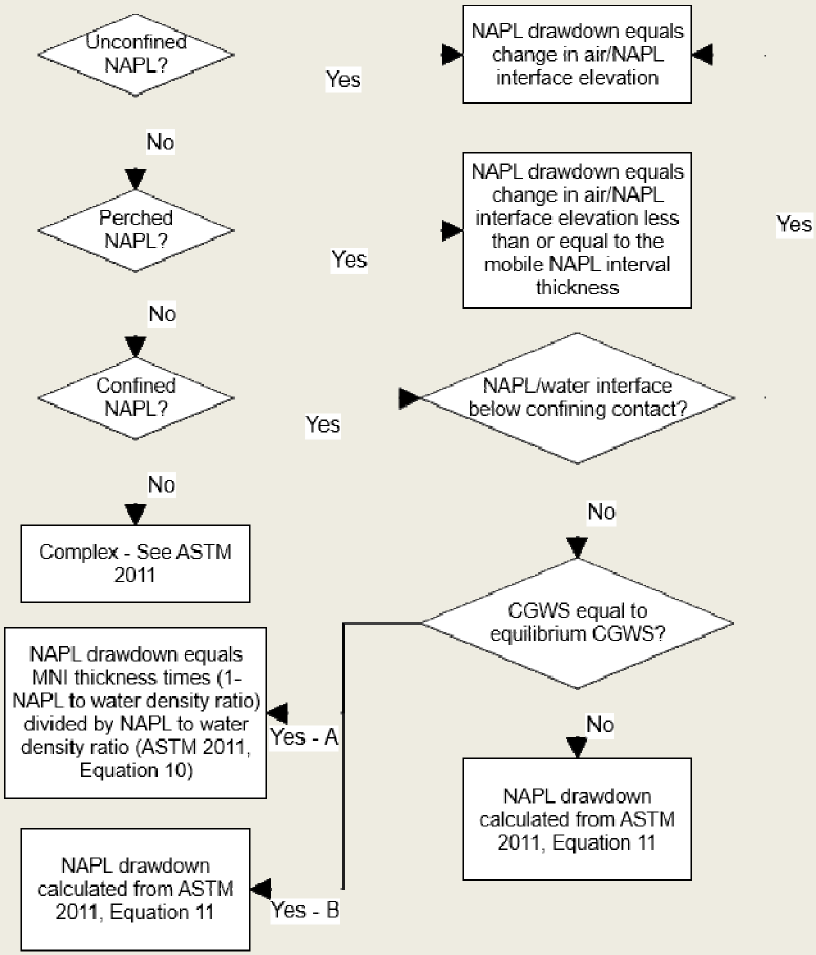




MNI: Mobile NAPL Interval
CGWS: Calculated Groundwater Surface

Hawthorne, J. Michael (2014) *Calculating NAPL Drawdown*, Applied NAPL Science Review, vol. 4, issue 3, September 2014

Gravity Pumping NAPL Drawdown



MNI: Mobile NAPL Interval
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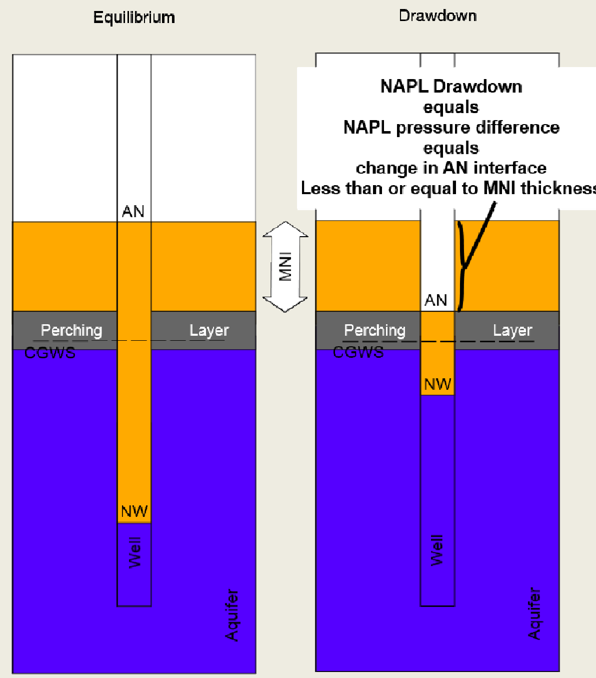
Perched NAPL



ASTM 2011, Equation 9:

$$s_{nt} = Z_{AN^*} - Z_{AN(t)}$$

$$for \quad s_{nt} \leq Z_{AN^*} - Z_{pc}$$

Where:

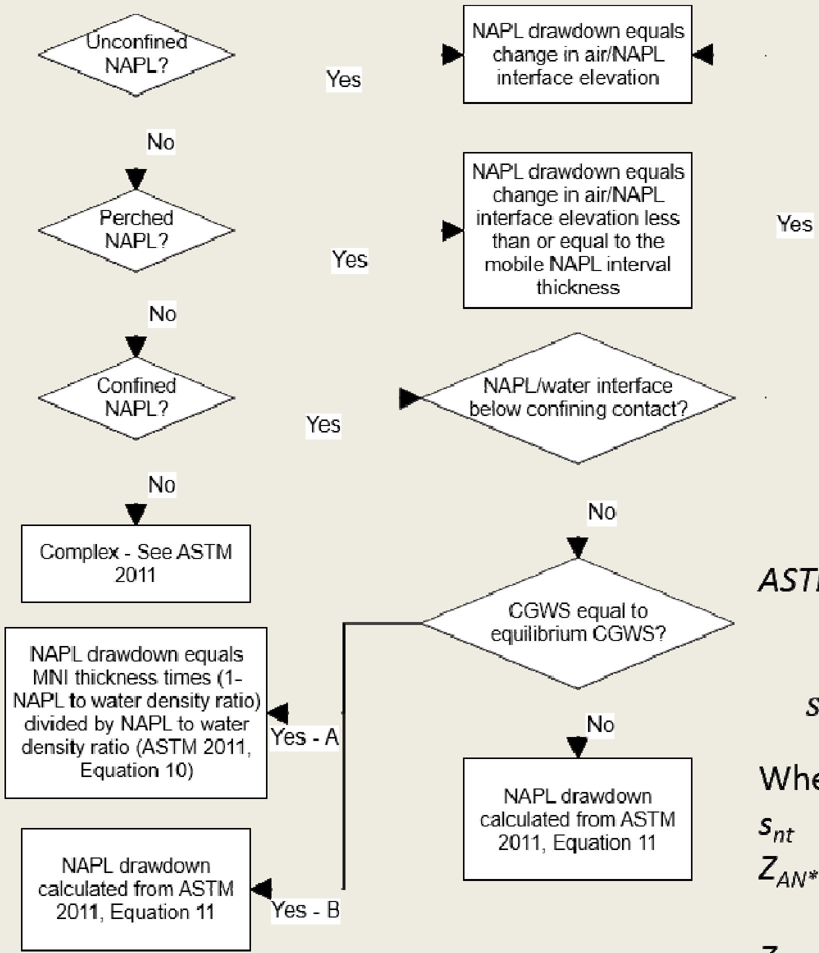
s_{nt} = NAPL drawdown at time t

Z_{AN^*} = air/NAPL interface elevation for equilibrium conditions

$Z_{AN(t)}$ = air/NAPL interface elevation at time t

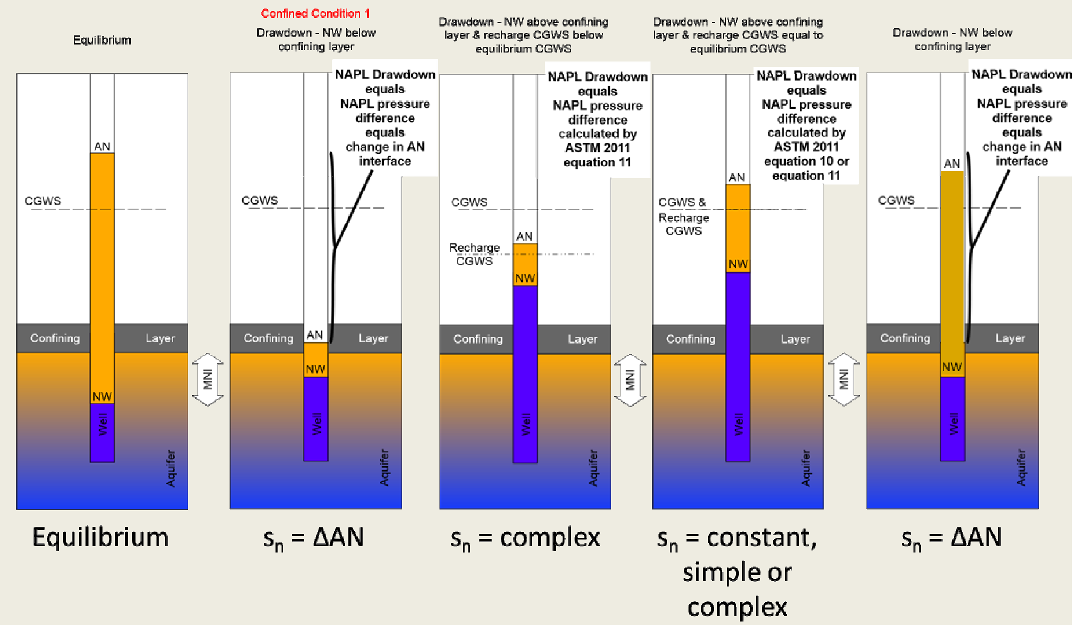
Z_{pc} = NAPL/perching layer contact elevation

Gravity Pumping NAPL Drawdown



MNI: Mobile NAPL Interval
CGWS: Calculated Groundwater Surface

Confined NAPL



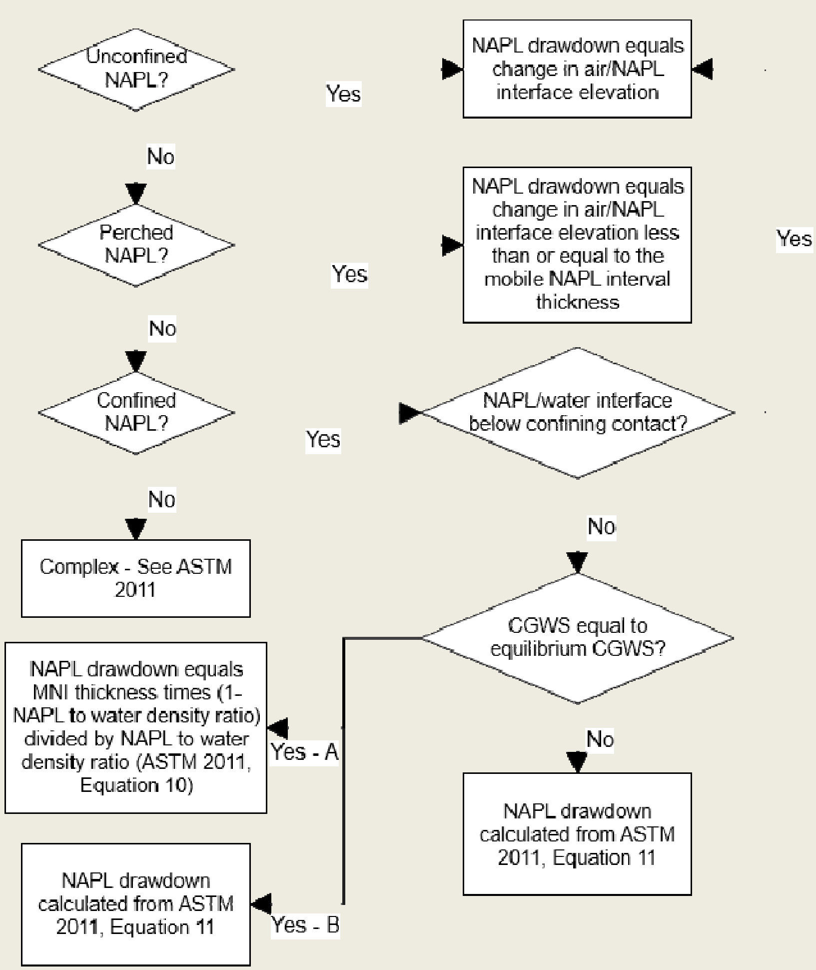
ASTM 2011 Equation 11 (generalized confined drawdown equation):

$$s_{nt} = \frac{(Z_{AN^*} - Z_{cc})\rho_n - (Z_{NW(t)} - Z_{cc})\rho_w - (Z_{AN(t)} - Z_{NW(t)})\rho_n}{\rho_n}$$

Where:

s_{nt}	=	NAPL drawdown at time t
Z_{AN^*}	=	the air/NAPL interface elevation for equilibrium conditions
Z_{cc}	=	NAPL/confining layer contact elevation
$Z_{NW(t)}$	=	NAPL/water interface elevation at time t
$Z_{AN(t)}$	=	air/NAPL interface elevation at time t
ρ_n	=	NAPL density
ρ_w	=	water density

Gravity Pumping NAPL Drawdown



MNI: Mobile NAPL Interval
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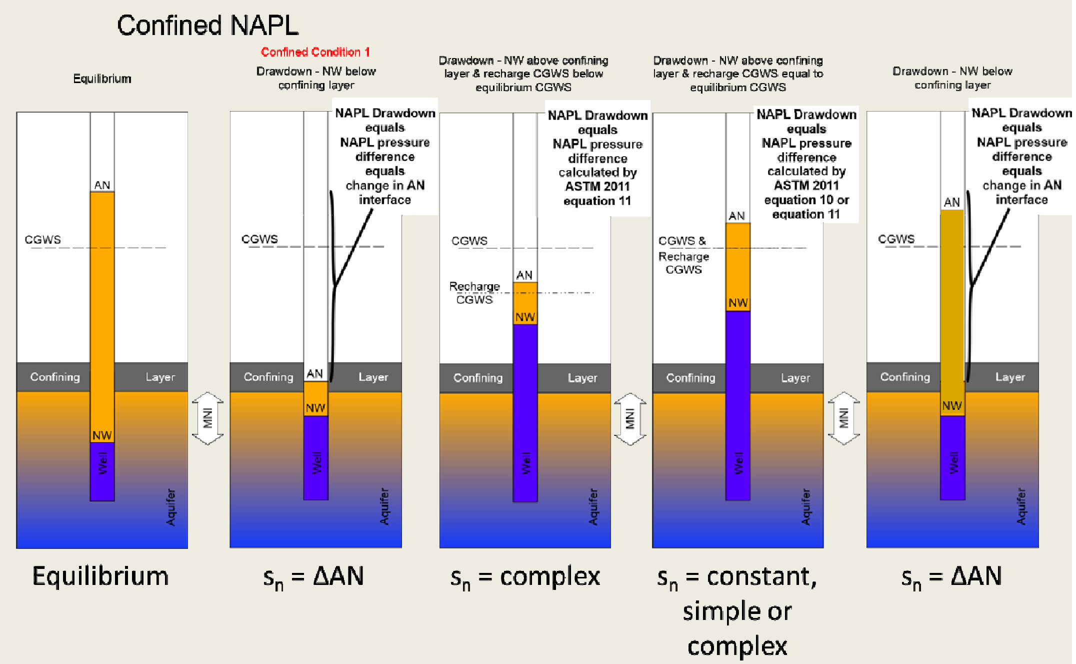


ASTM 2011 Equation 10 (simplified confined drawdown equation):

$$s_{nt} = b_{nf}\frac{1-\rho_r}{\rho_r}$$

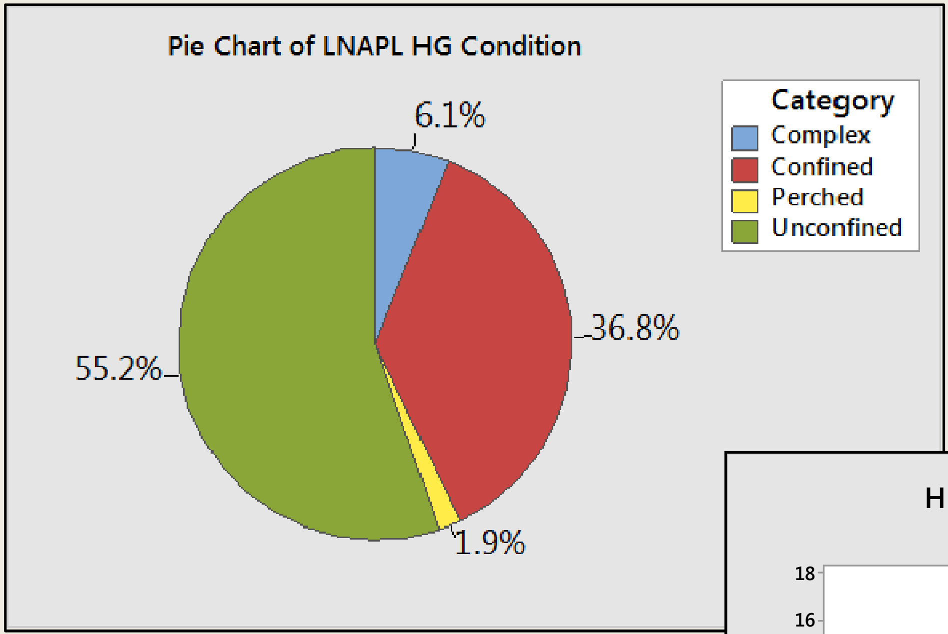
Where:

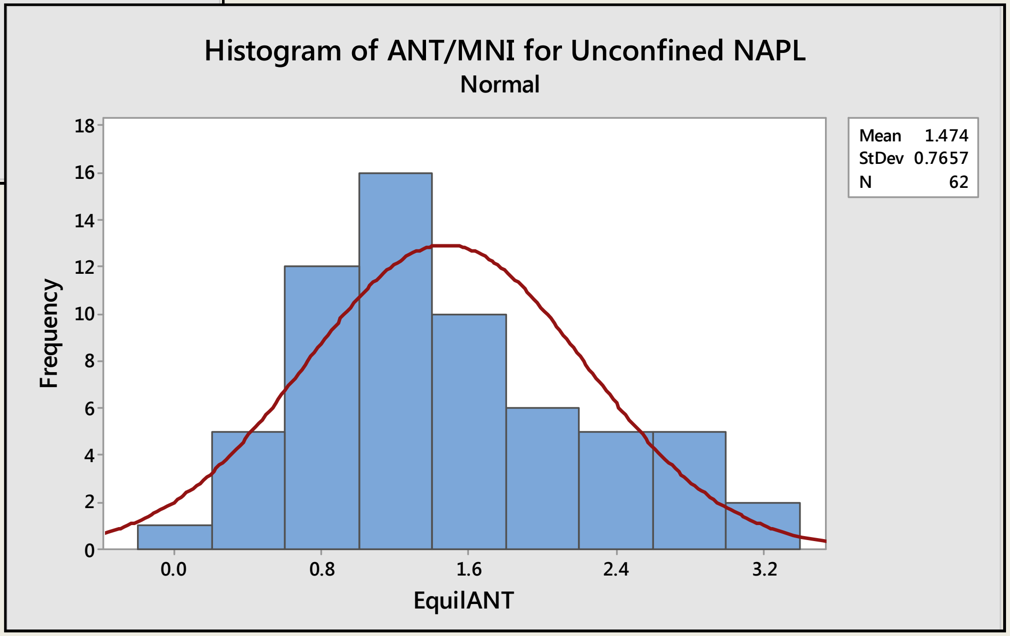
s_{nt} = NAPL drawdown at time t

b_{nf} = mobile NAPL interval thickness in the formation (not the same as the gauged apparent NAPL thickness)

ρ_r = NAPL/water density ratio

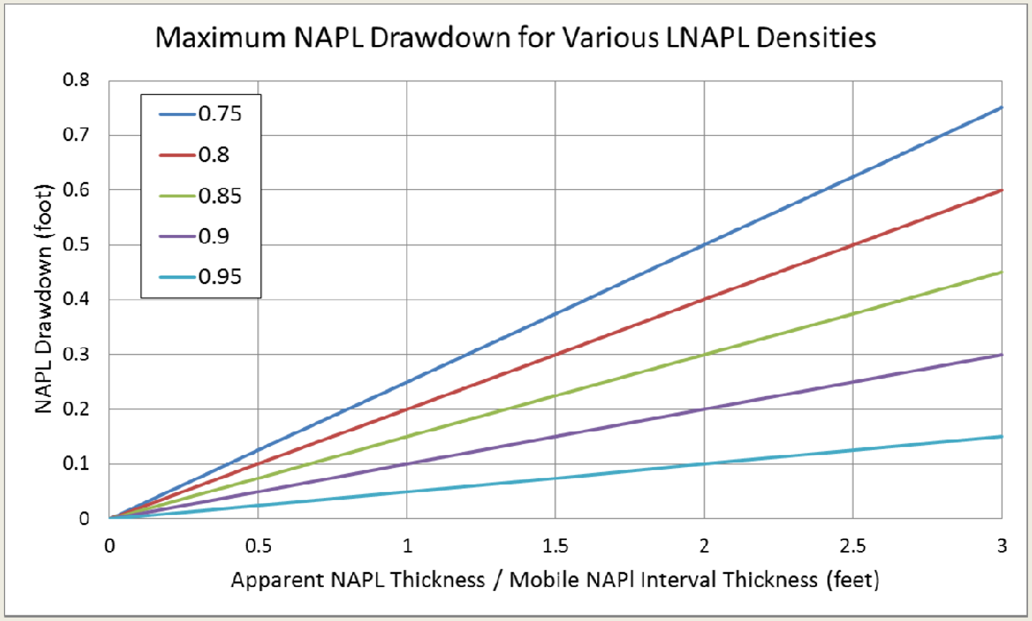
What is the frequency and magnitude of unconfined LNAPL?

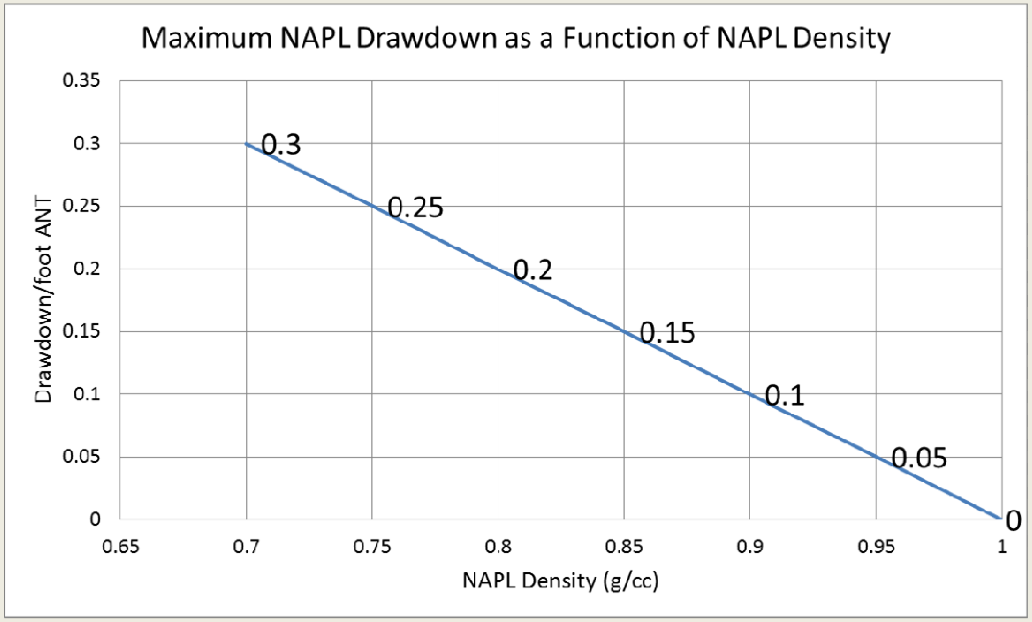




Hawthorne, J. Michael, Dennis Helsel and Charles Stone (2015) *Nationwide Statistical Analysis of LNAPL Transmissivity*, unpublished research conducted by H_2A Environmental, Ltd. on behalf of The American Petroleum Institute

What are realistic Ranges of NAPL Drawdowns for unconfined NAPL?



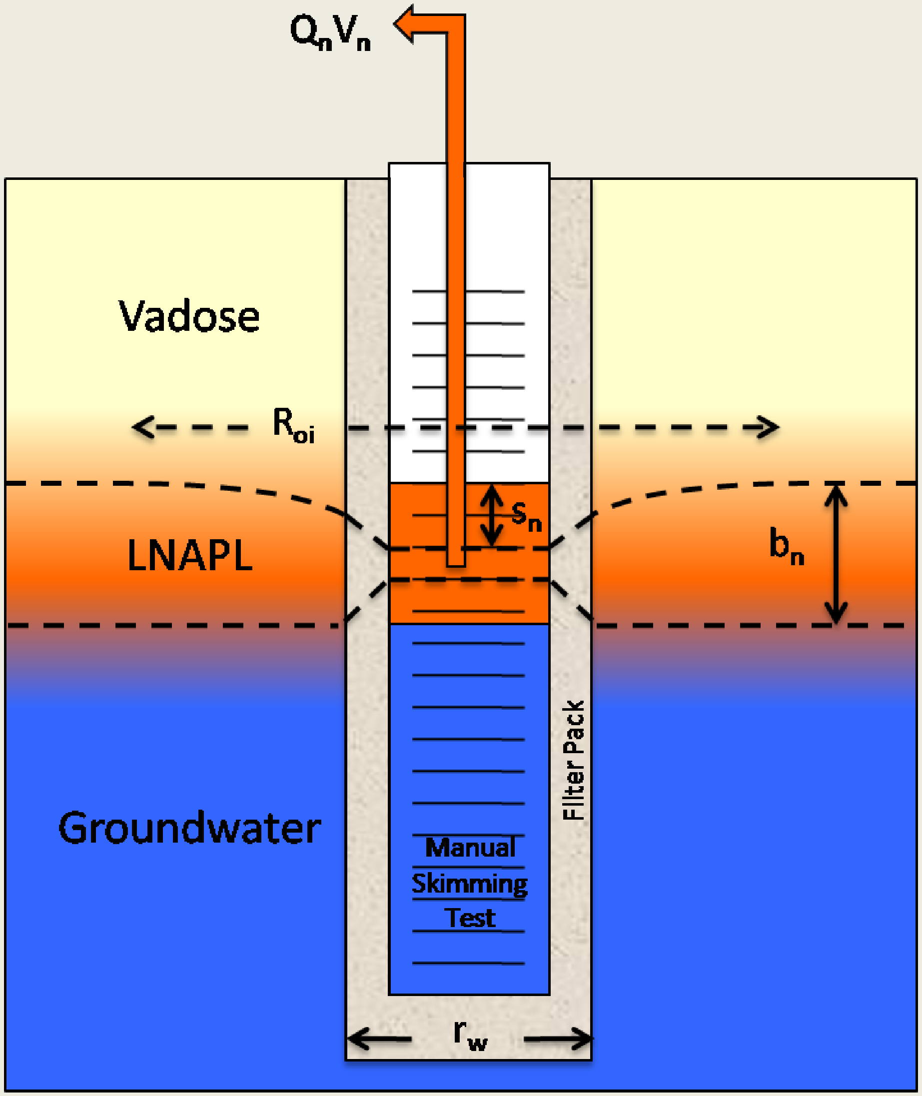


Why is manual skimming sensitive to s_n?

$$T_n = \frac{Q_n \ln \frac{R_{oi}}{r_w}}{2\pi\, s_n}$$

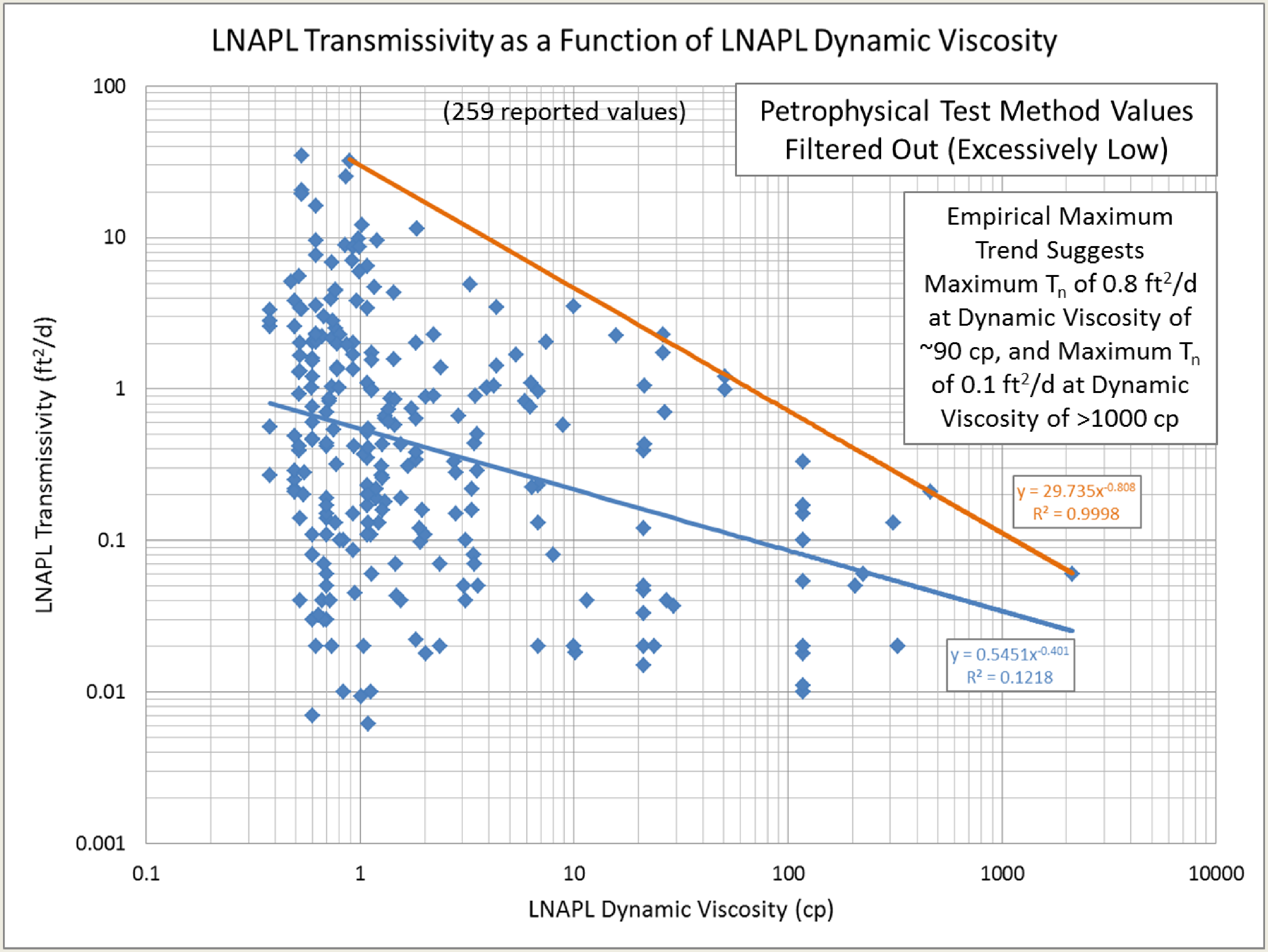
Generally safe to assume $\ln(R_{oi}/r_w) = 4.6$, so equation simplifies to:

$$T_n = 0.732 \frac{Q_n}{s_n}$$



Hawthorne, J. Michael (2014) *LNAPL Transmissivity (T_n): Remediation Design, Progress and Endpoints*, Texas Commission on Environmental Quality Annual Trade Fair and Conference, May 2010

Charbeneau, Randall (2007) *LNAPL Distribution and Recovery Model Volume 1: Distribution and Recovery of Petroleum Hydrocarbon Liquids in Porous Media*, Publication No. 4760, The American Petroleum Institute



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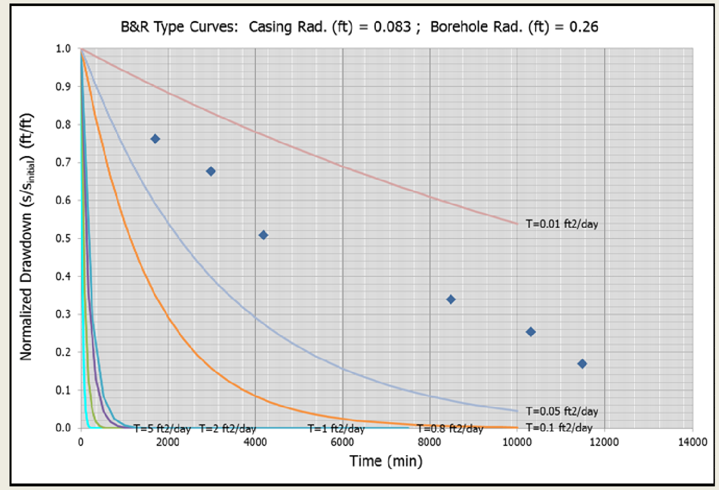
What are some common conditions that help or hurt the ability to accurately measure T_n?

"Helpful" Conditions (any method)	"Hurtful" Conditions (OWR beneficial)
Low density LNAPL	High density LNAPL
Low dynamic viscosity	High dynamic viscosity
High NAPL saturation	Low NAPL saturation
High hydraulic conductivity	Low hydraulic conductivity
Rapid NAPL recharge (short time)	Slow NAPL recharge (long time)
SUM: High T_n with low density	SUM: Low T_n with high density
Small relative groundwater fluctuations	Large relative groundwater fluctuations

Type curves to analyze and plan T_n testing

Charbeneau, Randall, Andrew J. Kirkman and Rangaramanujam Muthu (2012) LNAPL Transmissivity Baildown Spreadsheet, Draft API Publication



Manual Skimming Testing - Calculation of LNAPL Transmissivity

Applied NAPL Science Review (February 2012)

Drawdown (S_n) in feet; LNAPL skimming rate (Q_n) in gallons per hour; and LNAPL transmissivity (T_n) in feet squared per day

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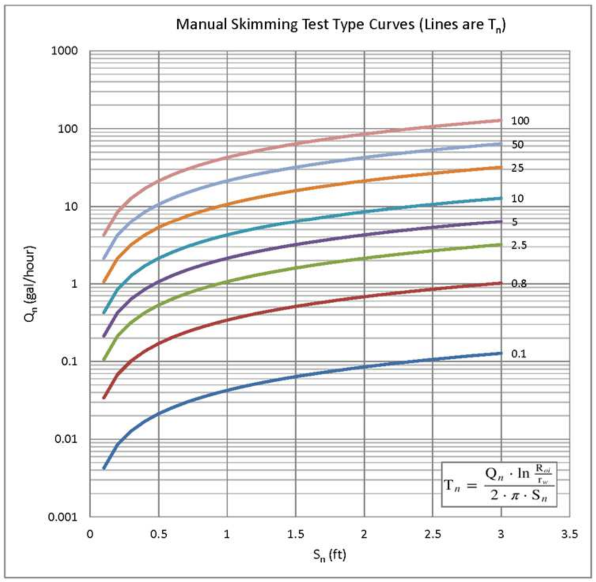
$S_n \backslash T_n$	0.1	0.8	2.5	5	10	25	50	100
0.1	0.004	0.03	0.11	0.2	0.4	1.1	2.1	4.3
0.2	0.009	0.07	0.21	0.4	0.9	2.1	4.3	8.5
0.3	0.013	0.10	0.32	0.6	1.3	3.2	6.4	12.8
0.4	0.017	0.14	0.43	0.9	1.7	4.3	8.5	17.0
0.5	0.021	0.17	0.53	1.1	2.1	5.3	10.6	21.3
0.6	0.026	0.20	0.64	1.3	2.6	6.4	12.8	25.5
0.7	0.030	0.24	0.75	1.5	3.0	7.5	14.9	29.8
0.8	0.034	0.27	0.85	1.7	3.4	8.5	17.0	34.1
0.9	0.038	0.31	0.96	1.9	3.8	9.6	19.2	38.3
1	0.043	0.34	1.06	2.1	4.3	10.6	21.3	42.6
1.1	0.047	0.37	1.17	2.3	4.7	11.7	23.4	46.8
1.2	0.051	0.41	1.28	2.6	5.1	12.8	25.5	51.1
1.3	0.055	0.44	1.38	2.8	5.5	13.8	27.7	55.3
1.4	0.060	0.48	1.49	3.0	6.0	14.9	29.8	59.6
1.5	0.064	0.51	1.60	3.2	6.4	16.0	31.9	63.9
1.6	0.068	0.54	1.70	3.4	6.8	17.0	34.1	68.1
1.7	0.072	0.58	1.81	3.6	7.2	18.1	36.2	72.4
1.8	0.077	0.61	1.92	3.8	7.7	19.2	38.3	76.6
1.9	0.081	0.65	2.02	4.0	8.1	20.2	40.4	80.9
2	0.085	0.68	2.13	4.3	8.5	21.3	42.6	85.1
2.1	0.089	0.72	2.24	4.5	8.9	22.4	44.7	89.4
2.2	0.094	0.75	2.34	4.7	9.4	23.4	46.8	93.7
2.3	0.098	0.78	2.45	4.9	9.8	24.5	49.0	97.9
2.4	0.102	0.82	2.55	5.1	10.2	25.5	51.1	102.2
2.5	0.106	0.85	2.66	5.3	10.6	26.6	53.2	106.4
2.6	0.111	0.89	2.77	5.5	11.1	27.7	55.3	110.7
2.7	0.115	0.92	2.87	5.7	11.5	28.7	57.5	114.9
2.8	0.119	0.95	2.98	6.0	11.9	29.8	59.6	119.2
2.9	0.123	0.99	3.09	6.2	12.3	30.9	61.7	123.5
3	0.128	1.02	3.19	6.4	12.8	31.9	63.9	127.7

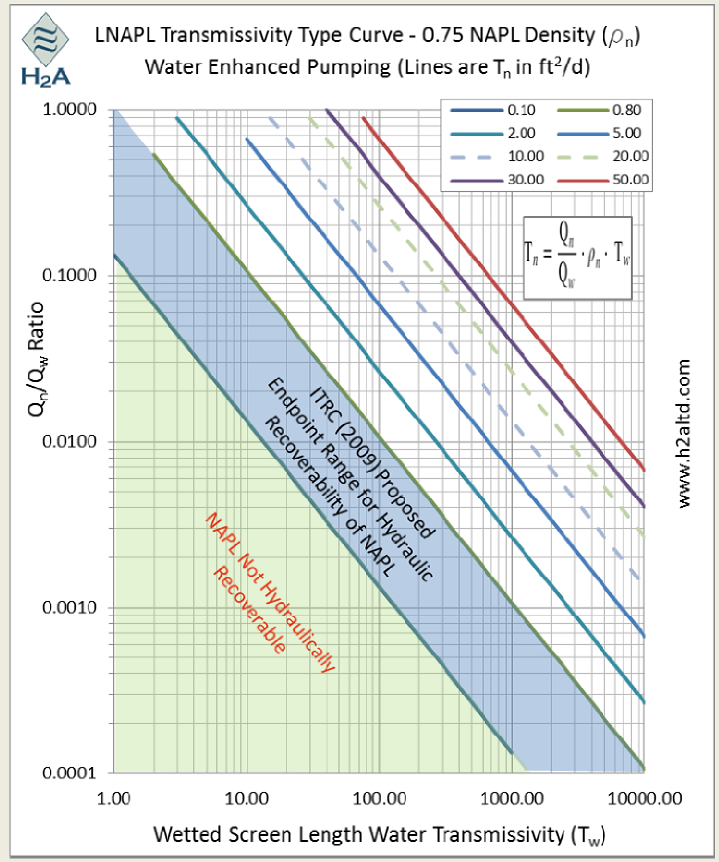
Q_n Key (gph)	<0.01	0.01 - 0.1	0.1 - 1	1 - 10	10 - 100	>100



$$T_n = \frac{Q_n \cdot \ln \frac{R_{oi}}{r_w}}{2 \cdot \pi \cdot S_n}$$

INSTRUCTIONS: Table and graph are based on the skimming equation for the calculation of LNAPL transmissivity. Three primary variables are incorporated - drawdown (S_n in feet), LNAPL pumping rate (Q_n in gallons per hour) and LNAPL transmissivity (T_n in feet squared per day). The table and graph may be used in any direction where any two variables are used to determine the third variable (e.g., drawdown and LNAPL skimming rate may be used to estimate LNAPL transmissivity, or if LNAPL transmissivity and drawdown are known, then the LNAPL skimming rate may be estimated). Assumes the value of ln R_{oi}/r_w is equal to 4.6 (see ASTM International *Standard Guide for Estimation of LNAPL Transmissivity*, January 2012, Section 8.2.1, Note 2).

Users of this reference guide should confirm its applicability prior to use. User assumes all liability associated with use of this guide.



Keys to selecting the "optimal" site-specific T_n measurement method

- **Know the NAPL hydrogeologic condition**
- **Understand your objective – absolute or relative value for T_n?**
- Know Groundwater Fluctuation Duration and Magnitude
  - Use method with small duration relative to GW fluctuation duration
  - Use method with large s_n relative to GW fluctuation magnitude over the test duration
- If ANT<0.5 foot, consider OWR testing then MS (not BD)
- Critical zone is low T_n with high density and small ANT