Estimating NAPL Effective Hydraulic Conductivity and Potential Velocity in the Field Based on Laboratory Pore-Fluid Mobility Test Results

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OBJECTIVES

This study presents a screening-level calculation method to estimate the NAPL effective hydraulic conductivity (K_n) and NAPL velocity in the field (if mobile). The method is applicable to any NAPL mobility assessment.

BACKGROUND

Nonaqueous phase liquid (NAPL) mobility is important in NAPL site characterization, remedy selection, and remedial design.

CHALLENGE

Distinguishing whether NAPLs are migrating or stable under field conditions.

CUSTOMARY APPROACH

Laboratory NAPL mobility tests are performed using sediment or soil core samples containing NAPL. If no NAPL is produced from the mobility test using driving forces orders of magnitude stronger than field conditions (e.g., by centrifuge or "water-drive" method), NAPL in that test plug can be considered residual (i.e., immobile) under field conditions.

LIMITATIONS OF CUSTOMARY APPROACH

When laboratory test gradients are orders of magnitude stronger than field conditions, any tests that produce NAPL movement in the field are inconclusive in terms of judging whether NAPL is greater or less than residual saturation in the field.

OPPORTUNITY

The **rate of NAPL movement** in the laboratory provides quantitative insight into its mobility in the field.

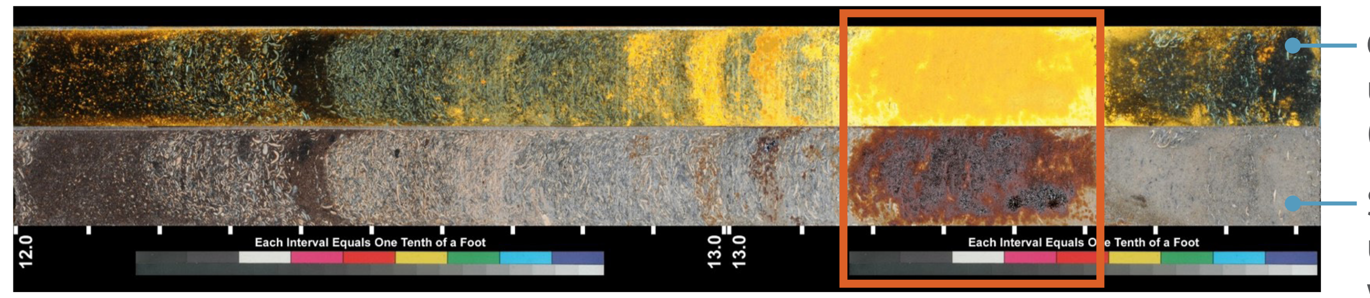
METHODS

APPROACH

- Test for NAPL mobility in soil or sediment using laboratory water-drive or centrifuge method.
- Apply constant hydraulic gradient for specific period of time (for water-drive method or centrifuge method). The results can be interpreted as follows:
  - No NAPL produced → NAPL effective hydraulic conductivity (K_n) = 0 (NAPL is at or below residual saturation and, therefore, immobile)
  - NAPL produced → calculate K_n
- For tests with multiple hydraulic gradients that are all significantly stronger than those in the field, use results for lowest test gradient.
- Apply K_n to calculate potential NAPL velocity if it is actually moving in the field (hypothetical assumption).

ACTIVITIES

1. Obtain test plug from soil or sediment sample (plug should be as undisturbed as practicable)
2. Apply hydraulic gradient and measure volume of NAPL produced from test plug
3. Obtain initial and final NAPL saturation, sample porosity, and test driving force from laboratory
4. Use Darcy's Law to calculate K_n

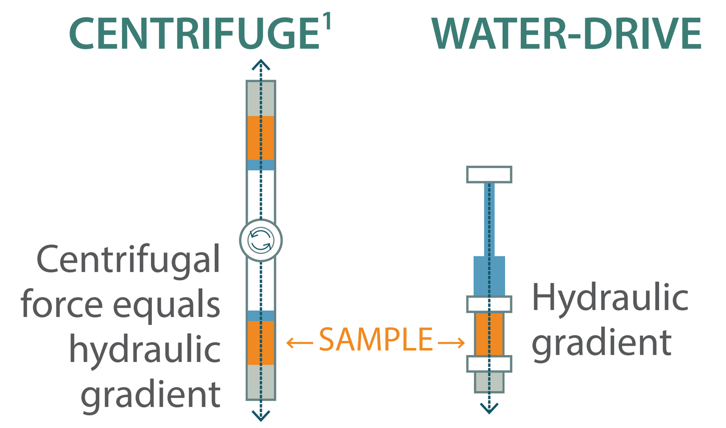


Core photo under UV light (NAPL fluoresces)

Same core photo under normal white light (NAPL is natural color)

SAMPLE

NAPL mobility test plug(s) normally taken from core interval(s) with highest apparent NAPL saturation



DETAILED VIEW

INITIAL

$V_{n,start}$ = NAPL volume at start of test

DURING TEST

Hydraulic gradient displaces some NAPL

ΔV_n

FINAL

$V_{n,end}$ = NAPL volume at end of test

NOTE

[1] For centrifuge tests, gradient = factor of gravity forces (e.g., 10G = hydraulic gradient of 10)

Calculation Approach	
Volume of NAPL in Test Plug	$V_n = V_t\, n\, S$
V_t = test plug volume; n = porosity; S = NAPL saturation	
Change in NAPL Volume	$\Delta V_n = V_{n,start} - V_{n,end}$
$V_{n,start} = V_n$ at start of test; $V_{n,end} = V_n$ at end of test	
NAPL Flow Rate	$Q_n = \Delta V_n / t$
t = test duration	
NAPL Effective Hydraulic Conductivity	$K_n = Q_n / Ai$ (Darcy's Law)
A = area of flow perpendicular to gradient; i = test hydraulic gradient	

Example Results

Example Results for Multi-Step Centrifuge Tests 10G, 100G, and 1000G Spin for 1 Hour Each		
Parameter	**Example 1**	**Example 2**
porosity, n	0.6585	0.458
NAPL saturation, S initial (%)	37.7	19.8
NAPL saturation, S after 10G (%)	36.7	19.8
NAPL saturation, S after 100G (%)	28.3	19.35
NAPL saturation, S after 1000G (%)	10.1	12.7
10G K_n (cm/s)	9.3E-07	0.0E+00
100G K_n (cm/s)	7.8E-07	2.9E-08
1000G K_n (cm/s)	1.7E-07	4.3E-08
Interpreted NAPL Mobility Condition	**Potentially Mobile**	**Residual**
Field NAPL Velocity Calculation ($v_n = K_n i$ / [nS])		
Field Hydraulic Gradient	0.005	0.005
Field NAPL Velocity (if mobile) (cm/s)	1.9E-08	0.0E+00
Field NAPL Velocity (if mobile) (cm/yr)	0.6	0

Example Results for Single-Step Centrifuge Tests 1000G Spin for 1 Hour		
Parameter	**Example 3**	**Example 4**
porosity, n	0.462	0.533
NAPL saturation, S initial (%)	29.2	9.3
NAPL saturation, S after 1000G (%)	14.2	9.3
1000G K_n (cm/s)	9.8E-08	0.0E+00
Interpreted NAPL Mobility Condition	**Potentially Mobile**	**Residual**
Field NAPL Velocity Calculation ($v_n = K_n i$ / [nS])		
Field Hydraulic Gradient	0.005	0.005
Field NAPL Velocity (if mobile) (cm/s)	3.6E-09	0.0E+00
Field NAPL Velocity (if mobile) (cm/yr)	0.11	0

CONCLUSIONS

- Calculated K_n values from 10G and single-step 1000G tests of polycyclic aromatic hydrocarbon (PAH)-rich NAPLs are usually in the range of 10^{-6} cm/sec or less. We have observed similar results from water-drive tests.
- PAH-rich NAPL field velocities estimated based on K_n, porosity, NAPL saturation, and field hydraulic gradient are often in the range of several centimeters per year or less.
- K_n values calculated based on 10G, 100G, and 1000G centrifuge tests are generally similar and sometimes show a sequential decrease in calculated K_n values from step to step. In these cases, the result from the first step (10G) is considered the most representative of the K_n value in the field because that test condition is closest to field hydraulic gradients and the sample is closest to its original condition.
- We have seen NAPL movement in samples with initial NAPL saturations as low as 2.5% with 1000G centrifuge and 3.7% with 100G centrifuge, demonstrating that these test conditions are too excessive to characterize NAPL residual saturation values in the field.

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