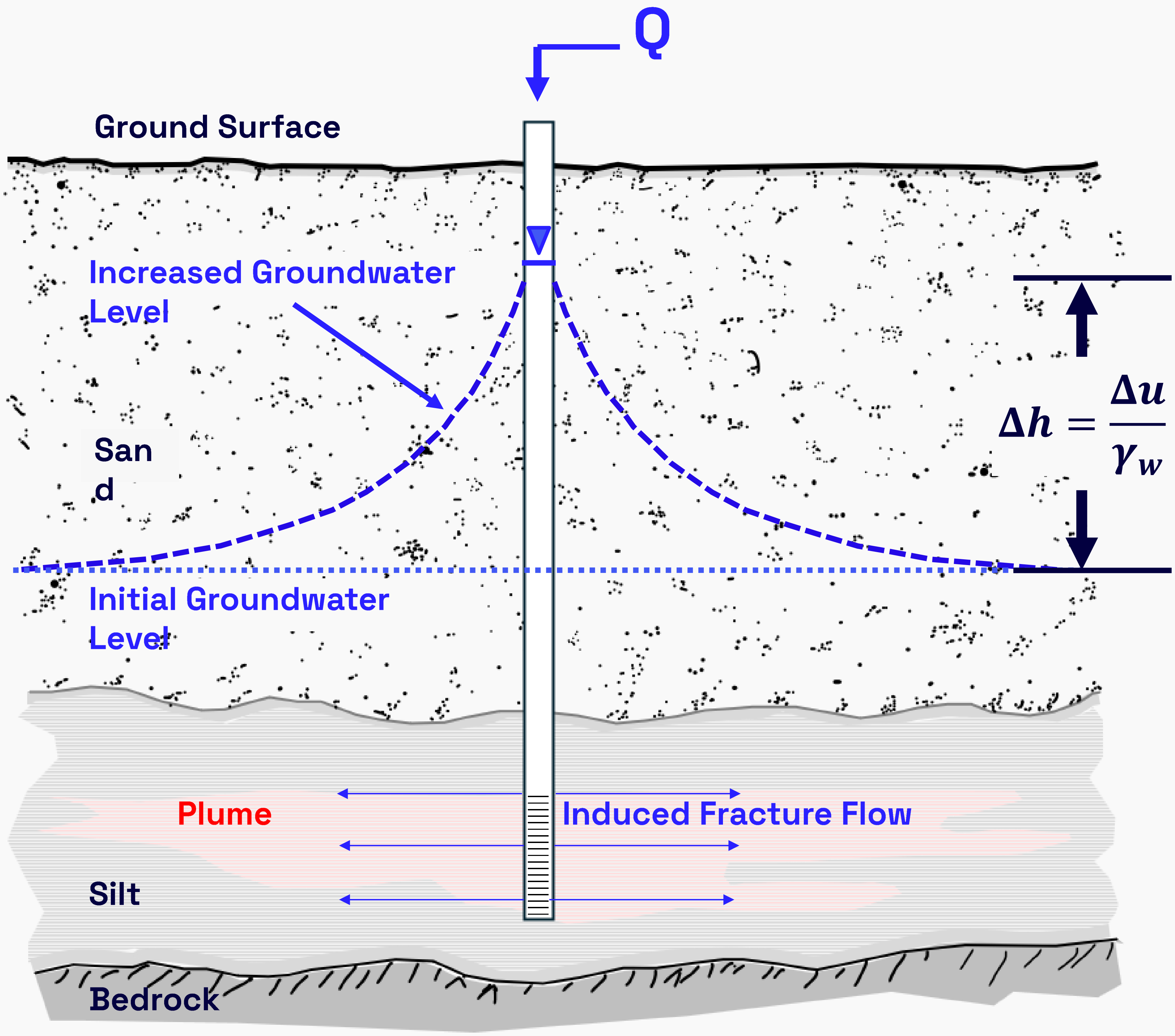
Induced Fracturing Pressures for Silt Remediation



Induced Fracturing

$$\Delta u_{frac} < \textbf{Injection Pressure} < \Delta u_{fluid}$$

When to use it

Use this to:

Estimate the saturated formation ("aquifer") pressure increase needed to intentionally initiate fractures in silt and sandy-silt, to temporarily increase permeability and improve amendment delivery for remediation.

What you will need

- Site lithology & unit weights (unsat/sat) for overburden load
- Soil friction angle (ϕ) for the relevant materials
- Initial groundwater levels and the expected change due to injection.
- Screen depth/interval

Important to note

- These equations apply to cohesionless soils only.
- This method targets formation pressure outside the screen, not casing pressure.
- For intentional fracturing, aim for a controlled pressure window: above fracture initiation but below fluidization.

Typical Applications

- Deliver oxygen-releasing amendments for enhanced bioremediation in low-K silt
- Deliver chemical oxidants/reductants when conventional injection will not distribute
- Create temporary pathways to reduce short-circuiting and improve contact with the plume matrix

Equations & Calculation Procedure

Step 1: Calculate the soil load above the screen

$$\sigma_v = \sum_i \gamma_i \, h_i$$

Step 2: Calculate the initial groundwater pressure at the screen

$$u_0 = \gamma_w \, h_w$$

Step 3: Calculate the initial vertical load carried by the soil grains

$$\sigma'_v = \sigma_v - u_0$$

Step 4: Calculate the initial horizontal load carried by the soil grains

For normally consolidated soils:

$$\sigma'_h = K_0 \, \sigma'_v \text{ where } K_0 = 1 - \sin\phi$$

For over-consolidated soils:

$$\sigma'_h = \sigma'_v (1 - \sin\phi) \, (OCR)^{\sin\phi}$$

Step 5: Calculate the pressure window for induced fracturing

1) Pressure increase that can start fractures: $\Delta u_{frac} = \sigma'_h$

2) Pressure increase that can fluidize the soil: $\Delta u_{fluid} = \sigma'_v$

Symbols Used

Symbol	Meaning	Typical units
Δu	Increase in groundwater pressure caused by injection	kPa
σ_v	Soil load above the top of screen from soil weight [total vertical stress]	kPa
u_0	Initial groundwater pressure at the top of screen [pore pressure]	kPa
σ'_v	Vertical load carried by the soil grains at the top of screen [vertical effective stress]	kPa
ϕ	Friction angle of the soil [effective friction angle]	°
K_0	Horizontal load ratio before injection (horizontal/vertical) [at-rest earth pressure coefficient]	–
σ'_h	Horizontal load carried by the soil grains at the top of screen [horizontal effective stress]	kPa
OCR	Over-consolidation ratio (only if using OC equation)	–
Δu_{frac}	Pressure increase that can start fractures [fracture initiation]	kPa
Δu_{fluid}	Pressure increase that can fluidize the soil where grains carry ~ zero load [effective vertical stress → 0]	kPa
γ_w	Unit weight of water (used to compute from head)	kN/m^3
γ_i	Unit weight of soil layer i (dry or saturated, as applicable)	kN/m^3
h_i	Thickness of soil layer	m
h_w	Height of water above the top of screen (to water level/potentiometric surface)	m

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Example Calculation

Background:
A remediation project requires injecting an amendment to improve treatment within a low-permeability formation. The target formation is silt (cohesionless). The stratigraphy consists of 6 m of sand over 3 m of silt. The aquifer is unconfined, with an initial groundwater level 5 m below ground surface. The injection well screen is set near the top of the silt layer. For this example, take the top of screen at 6 m below ground surface. Assume the formation is normally consolidated. The effective friction angle of the silt is $\phi = 26°$ .The sand unit weights are 18 kN/m³ (unsaturated) and 20 kN/m³ (saturated). Use $\gamma_w = 9.81$ kN/m³.

Task:
Estimate the formation pressure increase needed to initiate fractures in the silt, and the upper bound to avoid fluidization, at the top of screen. Convert both results to equivalent head rise.

Step 1: Calculate soil load above the screen $[\sigma_v]$

Above the screen you have:

- Unsaturated sand: 0–5 m → 5m
- Saturated sand: 5–6 m → 1m

$$\sigma_v = (18)(5) + (20)(1) = 90 + 20 = 110 \; kPa$$

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Example Calculation

Step 2: Calculate initial groundwater pressure at the screen $[u_0]$

Water head above screen:

$$h_w = z - z_{wt} = 6 - 5 = 1 \; m$$
$$u_0 = \gamma_w h_w = (9.81)(1) = 9.81 \; kPa$$

Step 3: Calculate vertical load carried by soil grains $[\sigma_v']$

$$\sigma_v' = \sigma_v - u_0 = 110 - 9.81 = 100.19 \; kPa$$

Step 4: Calculate lateral load carried by soil grains $[\sigma_h']$

$$K_0 = 1 - \sin(26^\circ) \approx 1 - 0.4384 = 0.5616$$

$$\sigma_h' = K_0 \sigma_v' = (0.5616)(100.19) = 56.27 \; kPa$$

Step 5: Calculate the induced fracturing window in terms of head

$$[\Delta u_{frac} = \sigma_h' = 56.27 \; kPa] \qquad \Delta h = \sigma_h' / \gamma_w = 56.27/9.81 = 5.7\text{m}$$

$$[\Delta u_{fluid} = \sigma_v' = 100.19 \; kPa] \qquad \Delta h = \sigma_v' / \gamma_w = 100.19/9.81 = 10.2\text{m}$$

Assessment:

For this example, fracture initiation begins at about 56.3 kPa (≈ 5.7 m head rise) and fluidization occurs at about 100.2 kPa (≈ 10.2 m head rise). Your operating target should stay between these two thresholds, based on field response and safety margin.