To Be or Not to Be a DUA?

A Critical Review of Procedures Used to Identify Domestic Use Aquifers

by

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OUTLINE

- Definition of a DUA
- Background
- Hydraulic Conductivity
  - Methods of estimation
  - Spatial variations and size effects
- Discussion
- Recommendation

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Why Identify a DUA?

- DUA: Domestic Use Aquifer, used to determine groundwater ingestion pathway
- Impacts on environmental practice: determining remediation guidelines

EX: Benzene concentration in groundwater for a coarse-grained site under residential/parkland land use

- 0.005 mg/L WITH DUA pathway included
- 0.140 mg/L DUA pathway excluded

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AENV Definition of a DUA (1/2)

Appendix E (AENV 2008), DUA:

- **Sustainable yield Q ≥ 0.76 L/min**

  with bulk K ≥ 10^{-6} m/s
  and sufficient geologic unit thickness b (> 0.5 m)

- **Used for domestic purpose**
- **Aquifer designated as DUA by AENV**

Boundary curves linking K and b

- **Confined / Unconfined Aquifer**

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AENV Definition of a DUA (2/2)

- **DUA pathway is excluded if:**
  - Saline groundwater: TDS > 4000 mg/L
  - Presence of natural geologic barrier :
    - At least 5 m of massive undisturbed unfractured fine-grained material
    - Bulk K ≤ 10^{-7} m/s

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Background (1/2)

- **Farvolden or Q_{20} Method (1959 unpublished report)**

  $$Q_{20} = 0.68 \times K \times b \times H_a \times 0.7$$

  - Q_{20}: sustainable yield (m^3/s)
  - K: bulk hydraulic conductivity (m/s)
  - b: aquifer thickness (m)
  - H_a: available head (m)
  - 0.7: safety factor (chosen by Farvolden)

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Background (2/2)

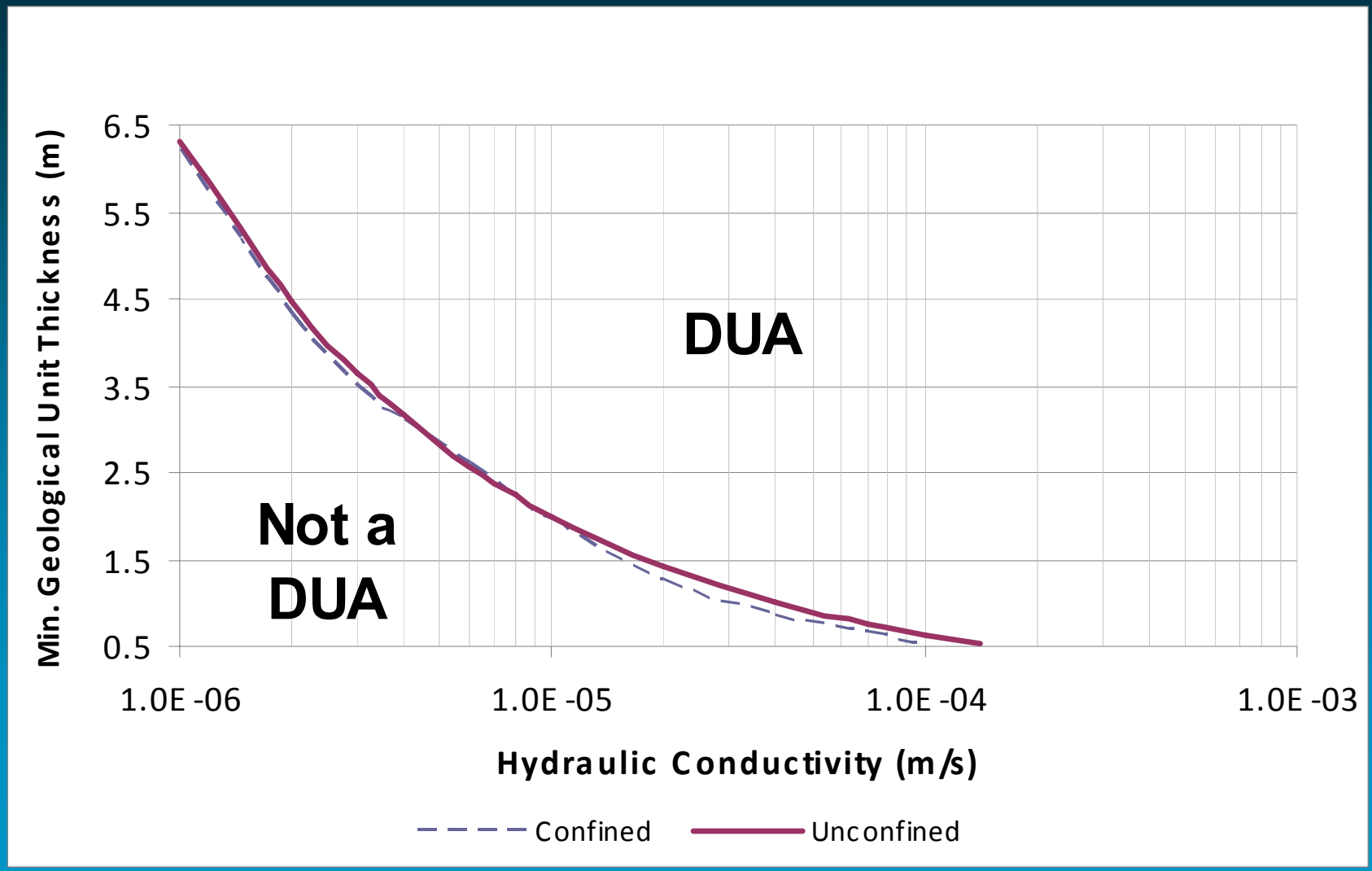
- **Limitations**
  - Theis' idealization assumptions
    - » Isotropic, homogeneous, infinite extent, fully confined aquifer
    - » Very few aquifers meet assumptions
  - No recharge
  - Some studies show that it overestimates long-term yield

AENV: Procedure to identify a DUA (1/3)

- **Methods suggested:**
  - Calculate sustainable yield: Q_{20} Method
  - Determine K: Pumping test or Slug test
- **To simplify calculations:**
  - Provided 2 boundary curves

    for confined and unconfined aquifer

AENV: Procedure to identify a DUA (2/3)



AENV: Procedure to identify a DUA (3/3)

$Q_{20}=0.68 \times K \times b \times H_a \times 0.7$

Unconfined aquifer

- Unknowns: b, K, H_a with H_a= 2/3b

Confined aquifer

- Unknowns: b, K, H_a
  - H_a : distance between the non-pumping water level and the top of aquifer; no further information provided

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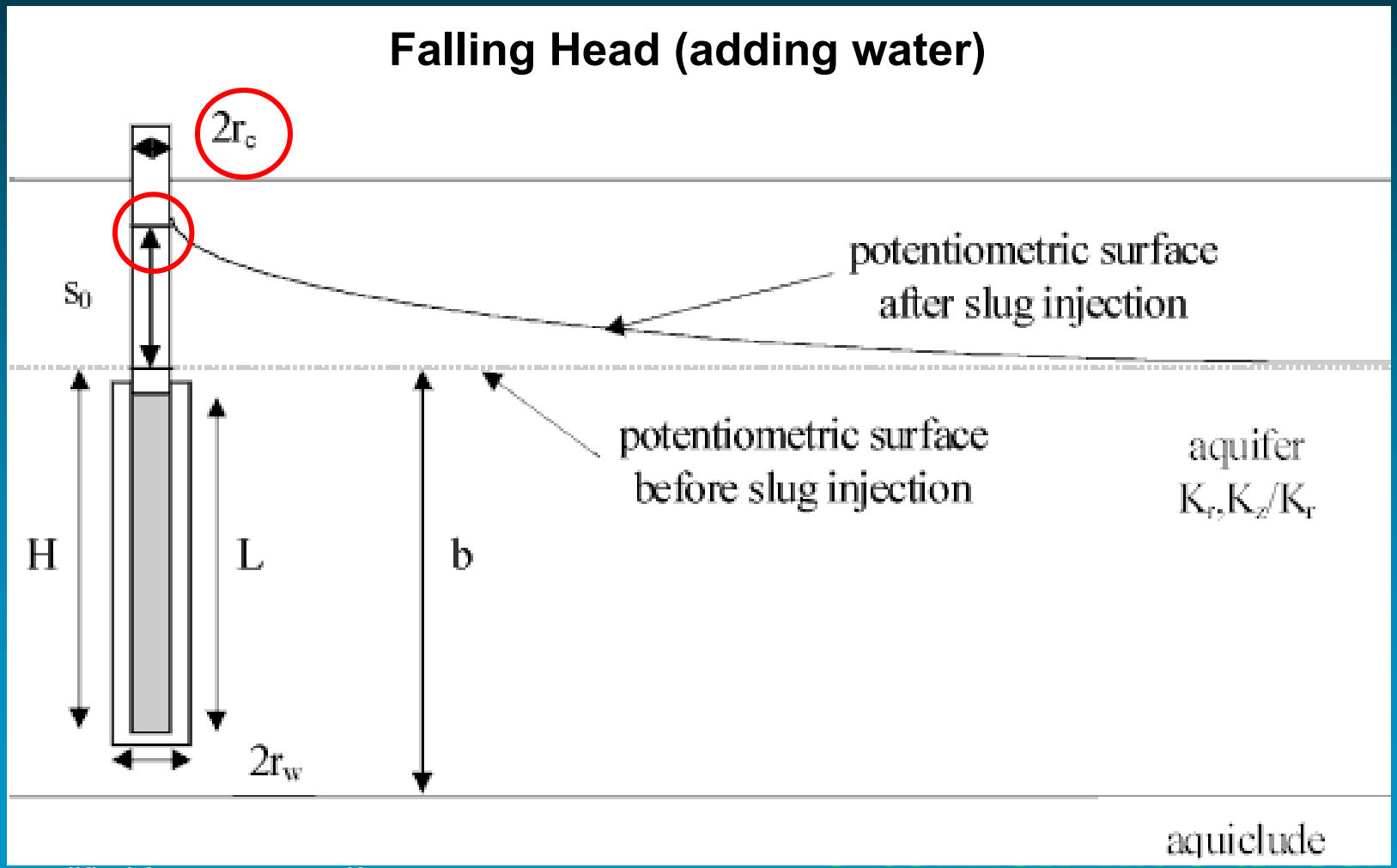
Common methods for determining K
General

- **Hydraulic conductivity K:**
  - K_x and K_y: K_h (horizontal)
  - K_z: K_v (vertical)
  - Anisotropy ratio K_h/K_v
- **K measured using field or laboratory methods**

Common methods for determining K

Slug Test (1/4)



Modified from www.aquifertest.com

Common methods for determining K
Slug Test (2/4)

Analysis Method	Aquifer Type	Well-Bore Skin	PP-Well	Kh/Kv	Formation Storage
Bouwer & Rice (1976) Bouwer (1989)	C/UC	N	Y	(PP)	N
Hvorslev (1955)	C/UC	N	Y	(PP)	N
Cooper et al. (1967)	C	N	N	N	Y
KGS (1994)	C/UC	Y	Y	Y	Y

C: Confined UC: Unconfined

Y: Yes ; N: No PP: Partially Penetrating

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Common methods for determining K
Slug Test (3/4)

- **Time-displacement data affected by:**
  - Flow direction
    - » Slug is introduced or removed
  - Nature of the aquifer
    - » Confined, unconfined, leaky; anisotropy
  - Well characteristics
    - » Well development

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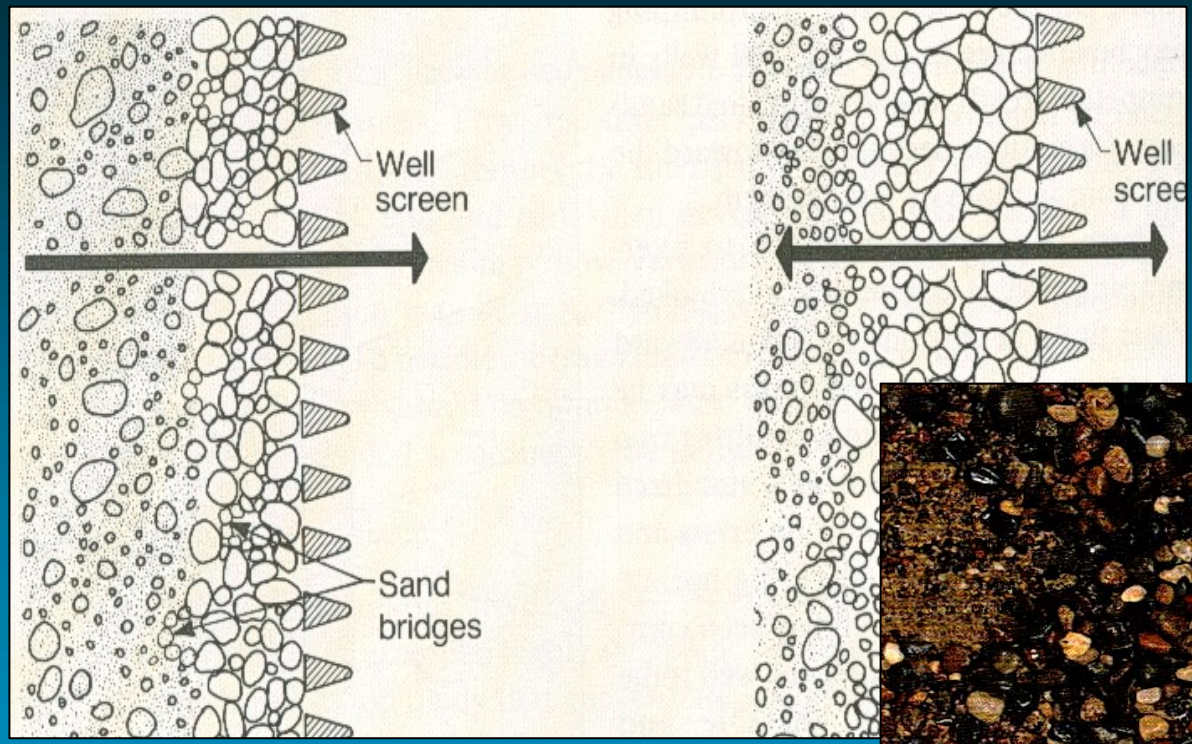
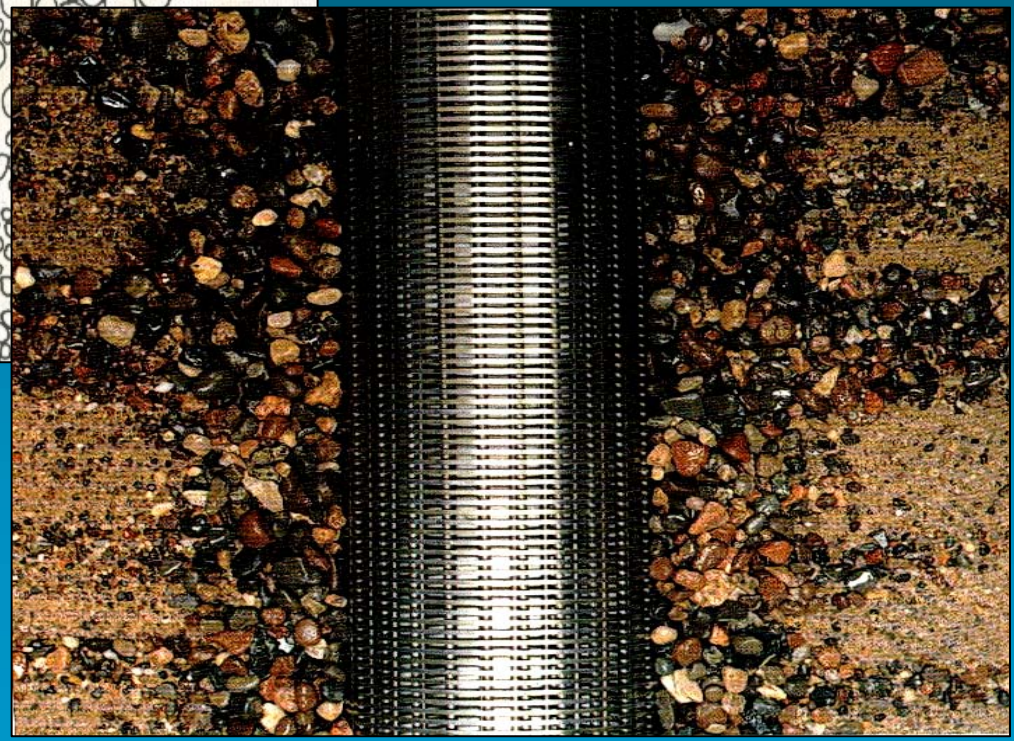
Common methods for determining K

Slug Test (4/4)





Importance of good well development

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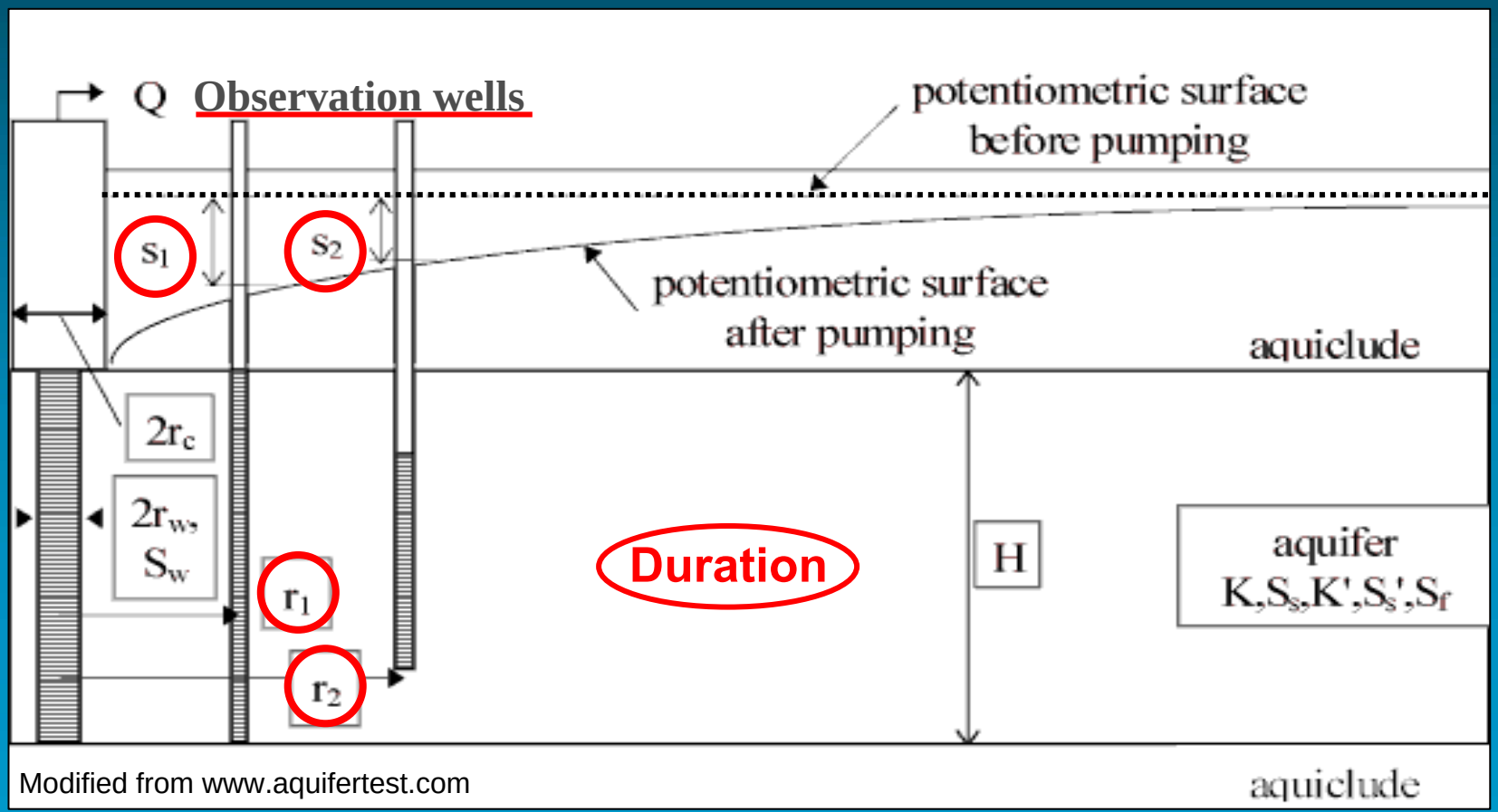
Common methods for determining K
Pumping Test (1/4)

- Conducted to identify Transmissivity and Storativity, and possible hydraulic boundaries



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Common methods for determining K
Pumping Test (2/4)

- **Observation wells help estimating:**
  - S and head losses
  - Directional dependence
  - Flow boundaries (e.g., river, lake)
  - Distance of observation well from pumping well:

$$r_{obs} > 2b(K_h/K_v)^{0.5}$$

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Common methods for determining K
Pumping Test (3/4)

- Near constant extraction rate
- Duration: depends on aquifer type
- Better data if pumping reaches steady or pseudo-steady state
- Important to record barometric pressure

Common methods for determining K
Pumping Test (4/4)

- Obtain K estimates by comparing the data with theoretical plots (straight-lines or type curves)
- Estimate K_h and S
- K_h/K_v and b can be estimated if partial penetrating wells used

Common methods for determining K
Other Methods (1/2)

Direct-push (DP) technologies

- Permeameter (DPP)
- Hydraulic Profiling Tool (HPT)
- Cone-Penetration Testing (CPT)

Geophysics

- Gamma, induction, neutron

Common methods for determining K
Other Methods (2/2)

Laboratory Methods

- Performed on small "undisturbed" soil samples: usually assess Kv
  - Constant-head permeameter
  - Falling-head permeameter
- Grain-size analysis (infer K bulk)
  - Correlation method (e.g. Hazen)

Scale Effect

Pumping test vs Slug test

	Pumping Test	Slug Test
Time	Hours to days	Minutes to hours
Radius	Regional scale	Local scale (≈1/10 regional scale)

- K (pumping test) > K (slug test) > K (laboratory) – size
- Other scale effects:
  natural scale dependence (e.g. fractures);
  uncertainties (e.g. aquifer thickness)

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Spatial variation in K

- The norm rather than the exception
- Can vary up to an order of magnitude for a formation at a given site
- K can varies between wells where tests were performed

Spatial variation in K
Stratified formations

- To treat layered lenticular and discontinuous units as a single hydrostratigraphic unit – use equivalent hydraulic conductivity $\overline{K}$

Flow parallel to the bedding planes

$$\overline{K} = \frac{\sum_{i-1}^{n} K_i h_i}{\sum_{i-1}^{n} h_i}$$

Flow perpendicular to the bedding planes

$$\overline{K} = \frac{\sum_{i-1}^{n} h_i}{\sum_{i-1}^{n} \frac{h_i}{K_i}}$$

Additional considerations regarding DUA identification

- K estimates:
  - Which method should we use to identify K?
  - How many wells are sufficient to assess K at a site – likely site-specific?
  - How to assess spatial variation in K?
- Importance of aquifer characteristics?

Conclusions: Recommended procedure

1) Formulate a “living” CSM
2) Determine stratigraphy and screen interval for in situ testing (use DP-HPT or geophysical logging for example)
3) Drill and install wells
4) Carry out in situ hydraulic testing
5) Obtain K using appropriate analysis methods

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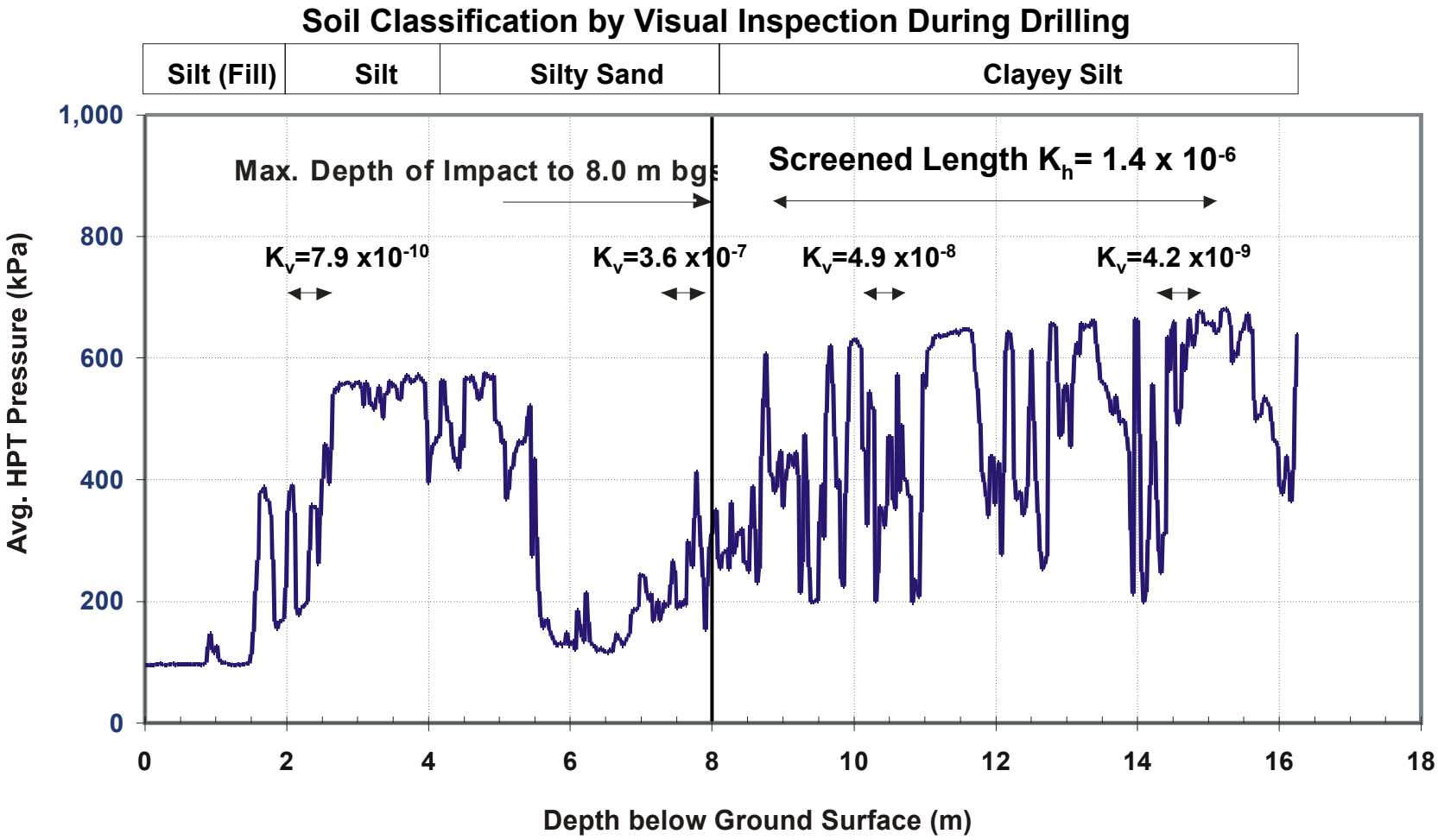
Conclusions: Recommended procedure

HPT Injection Pressure Profile and variations of K values with Depth



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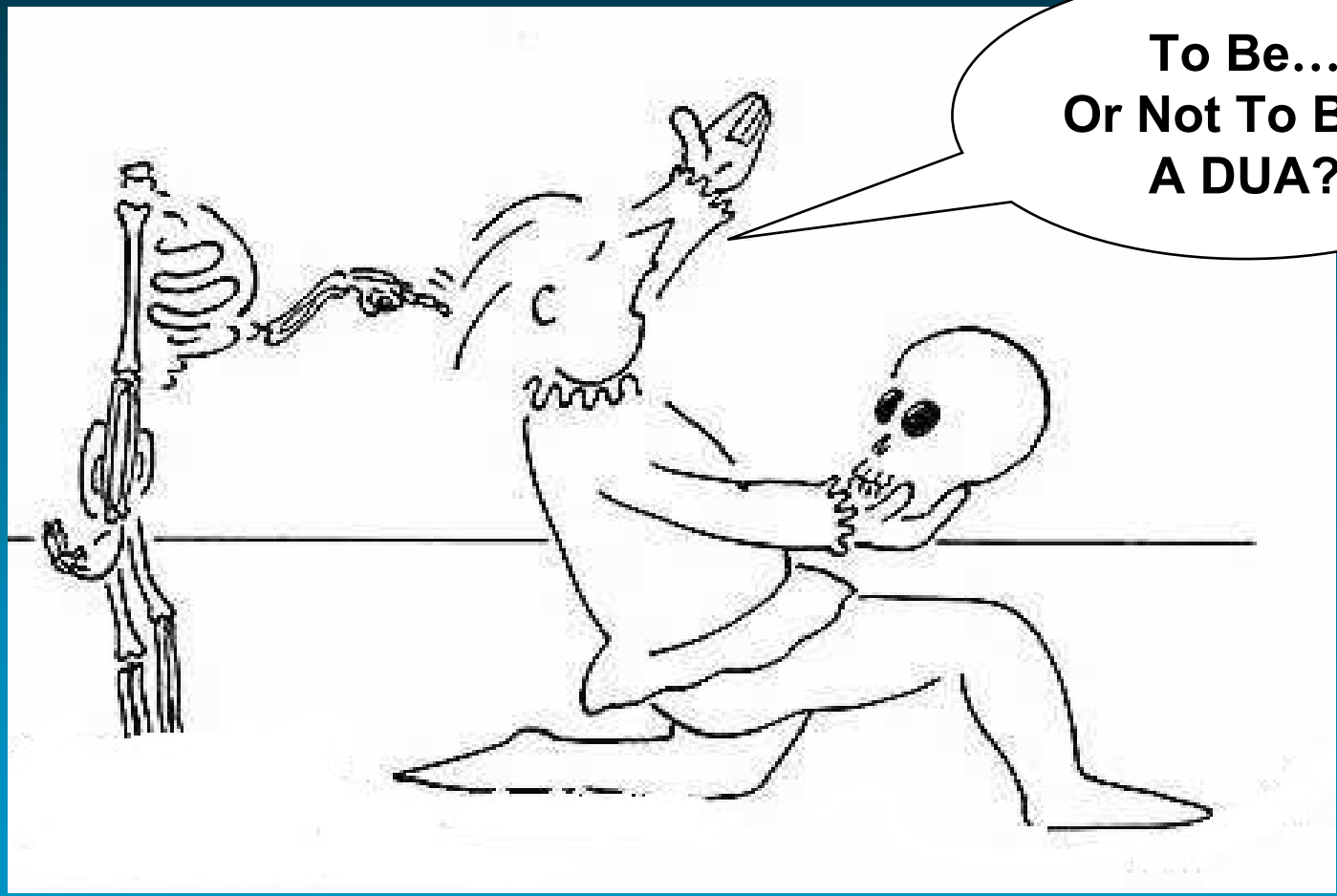

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Methods for determining K
Other Methods

Direct-push (DP) technologies

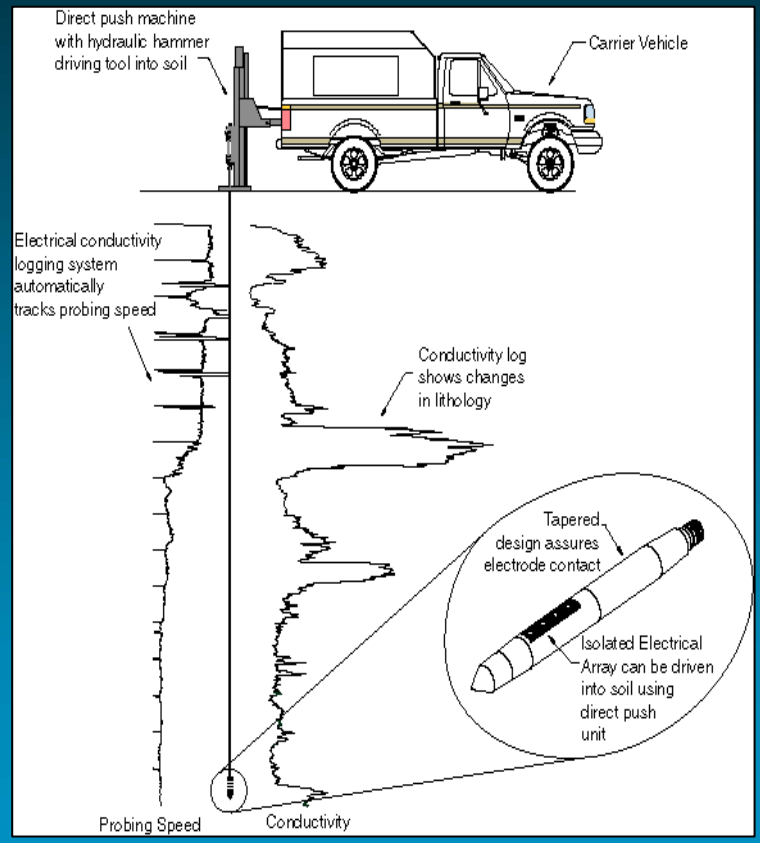
- **Basic Principles:**
  - Small diameter rod string with sensors
  - Pushed in subsurface
  - Using hydraulic ram (and High-frequency hammer)
  - Sampling tool: Shelby tube, dual tube samplers

Methods for determining K
Other Methods

Hydraulic profiling

➔Gives vertical profiles of lithological/ hydrological information

- HPT (+ EC)
- Can be used for direct slug testing



www.kgs.ku.edu

Methods for determining K
Other Methods

DP- Permeameter (DPP)

➔Gives vertical variations in K in shallow unconsolidated formations

- Hydraulic test – measures by transducers

Limits:

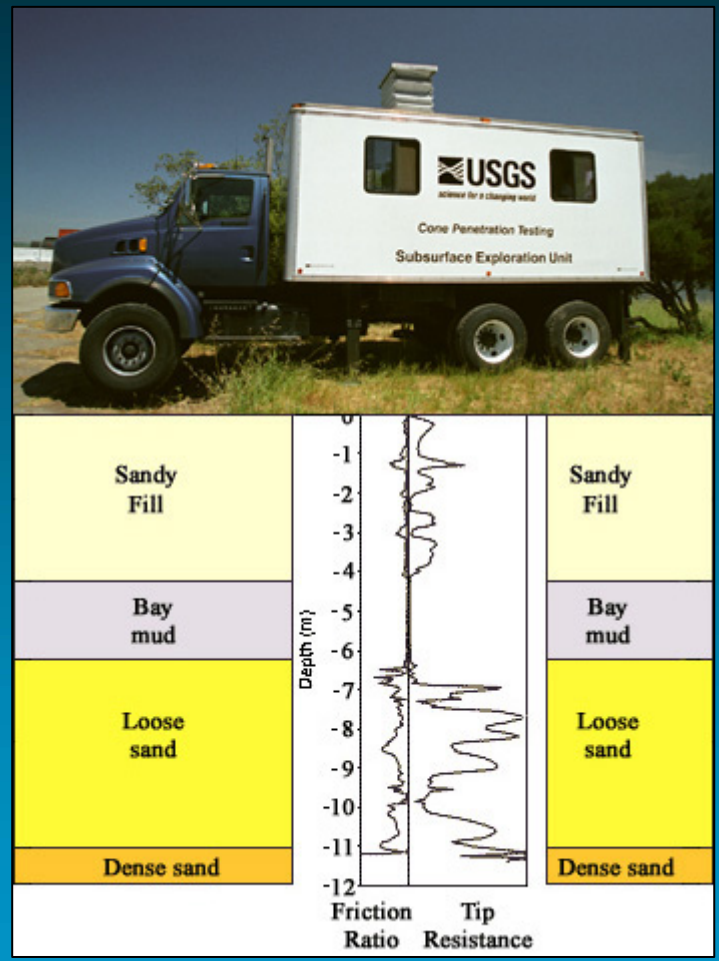
- Low depth achieved
- Vulnerability to media alteration

Methods for determining K
Other Methods

Cone-penetration testing (CPT)

➔Can sense stratigraphy, relative density, shear strength, resistivity…

- Measure the resistance on the tip of a conical point rod



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Methods for determining K

Other Methods

Geophysics

Downhole Log	Properties measured	Potential application	Radius of measurement
Natural Gamma	Natural gamma radiation	Lithology related to clay/silt content	6 to 12 in.
Neutron	Hydrogen content	Saturated porosity, moisture contents	6 to 12 in.
Induction	Electrical conductivity	Conductivity, changes in clay contents, permeability of fractures	30 in.

Methods for determining K

Other Methods

Natural gamma log and Electrical induction log