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Field Techniques for Quantifying the Vertical Permeability Characteristics of Oil Shale

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Why is Containment Important ?

Containment:

- Restricts ground water influx into process zone (increased heating efficiency)
- Prevents migration of produced gases during heating
- Protects overlying water quality from regulated hydrocarbon condensates as a result of gas migration
- Increases effectiveness of post-operational sub-surface reclamation activities
- Prevents post-operational migration of affected ground water that contacts process zone residuals

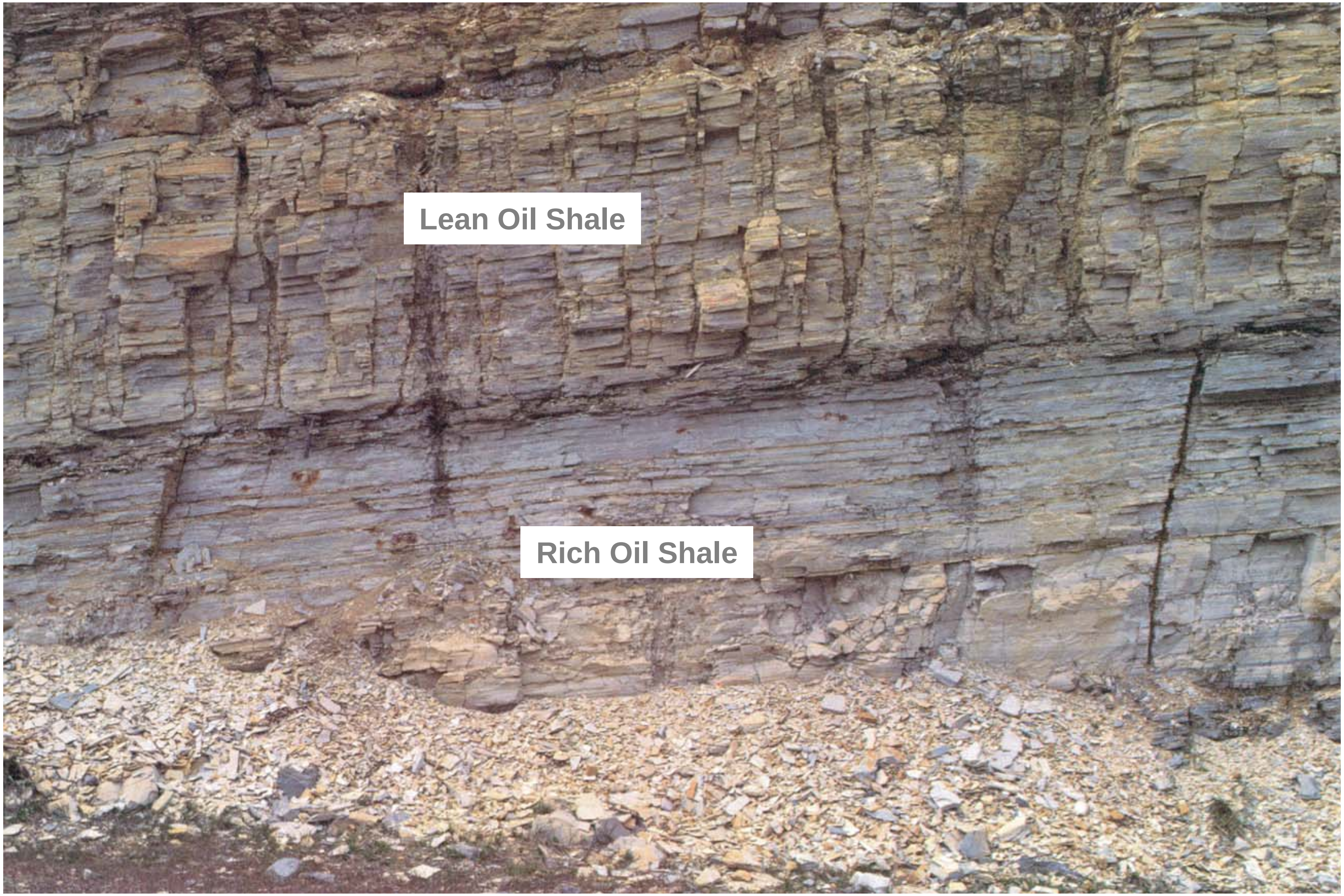
Requirements:

- **Lateral Containment:** Engineered (e.g. freeze wall) or geologic (e.g. within saline zone)
- **Vertical Containment:** Low vertical permeability geologic units or “seal intervals” for top and bottom containment (e.g. unfractured, laterally continuous oil shale intervals)

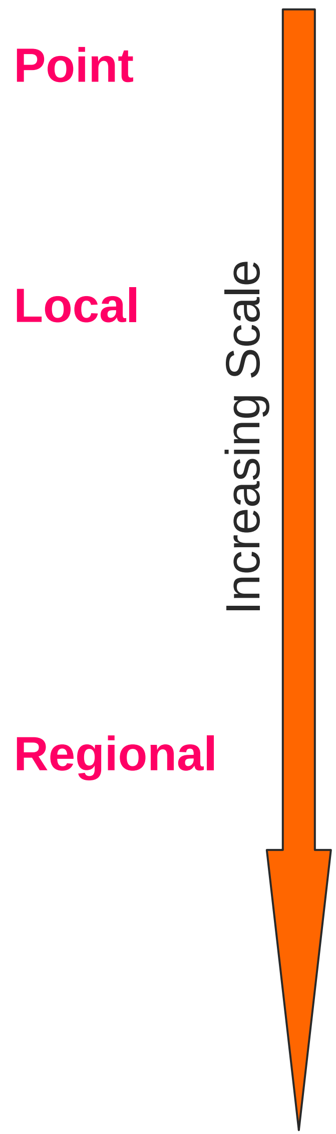
Geologic Containment Characteristics

- Laterally continuous
- Low vertical permeability
- Relatively free of vugs and fractures
- Maintains separation of hydrostratigraphic units during the operational and post-operational phases of an in-situ project
- Potential to influence ground water flow patterns and water quality on a regional scale

Rich & Lean Oil Shale

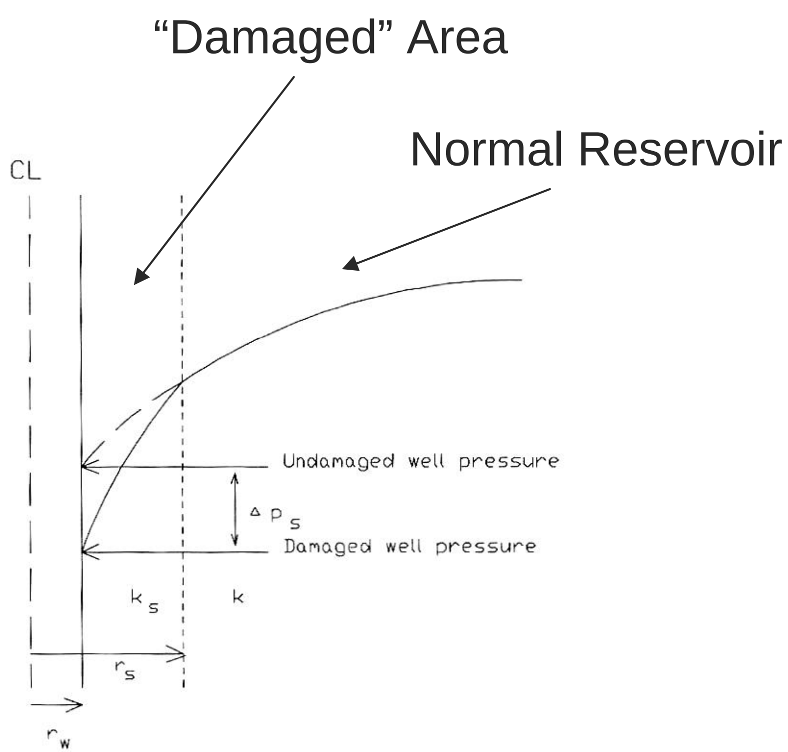


Available Methods for K_v Estimates

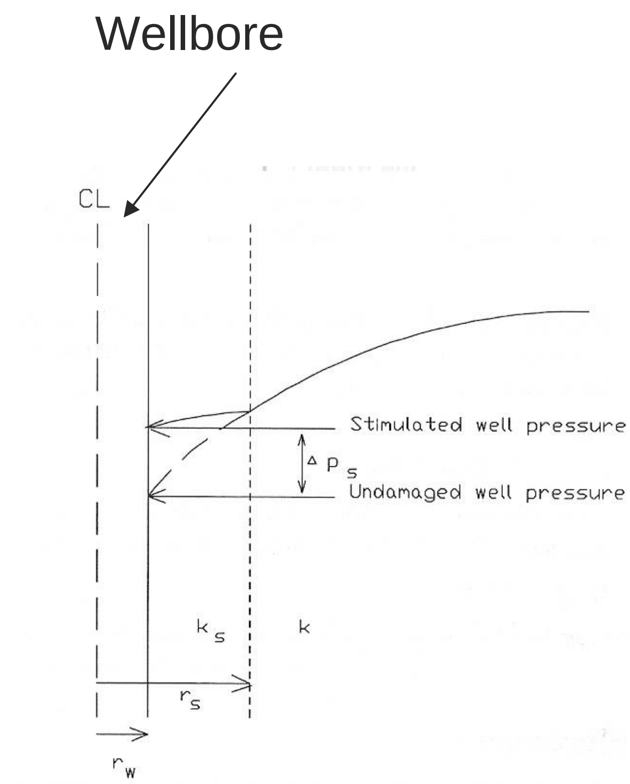


- **Laboratory permeability tests on core samples**
  - Secondary permeability features generally not included
  - Unfractured oil shale Kv ~ 10^{-5} ft/day
- **Field testing of coreholes and wells**
  - Packer-buildup (slug) tests (single drill holes)
  - Packer-pumping tests (single or multiple drill holes)
  - Clustered well tests
- **Water balance considerations (Basin Margins)**
  - Canyon-bounded areas provide “closed system”
  - Discharge = Steady-state vertical flow = $K_v * I_v$
- **Numerical flow model matches to observed vertical potentiometric head differentials**
  - K_v range: 10^{-5} to 10^{-3} ft/day.
  - Relatively unfractured, lower permeability intervals are dominant control on vertical ground water flow.

Well Testing – Well Damage (Skin)



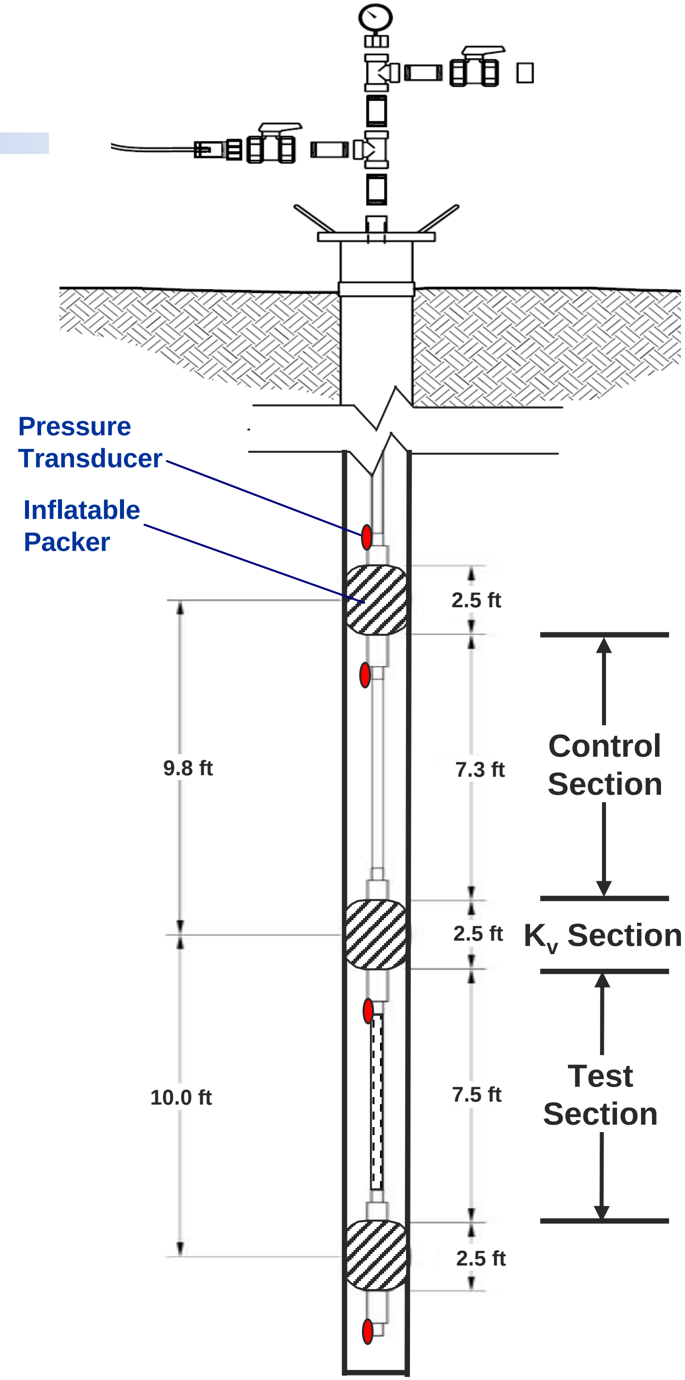
Positive Skin (Damage)



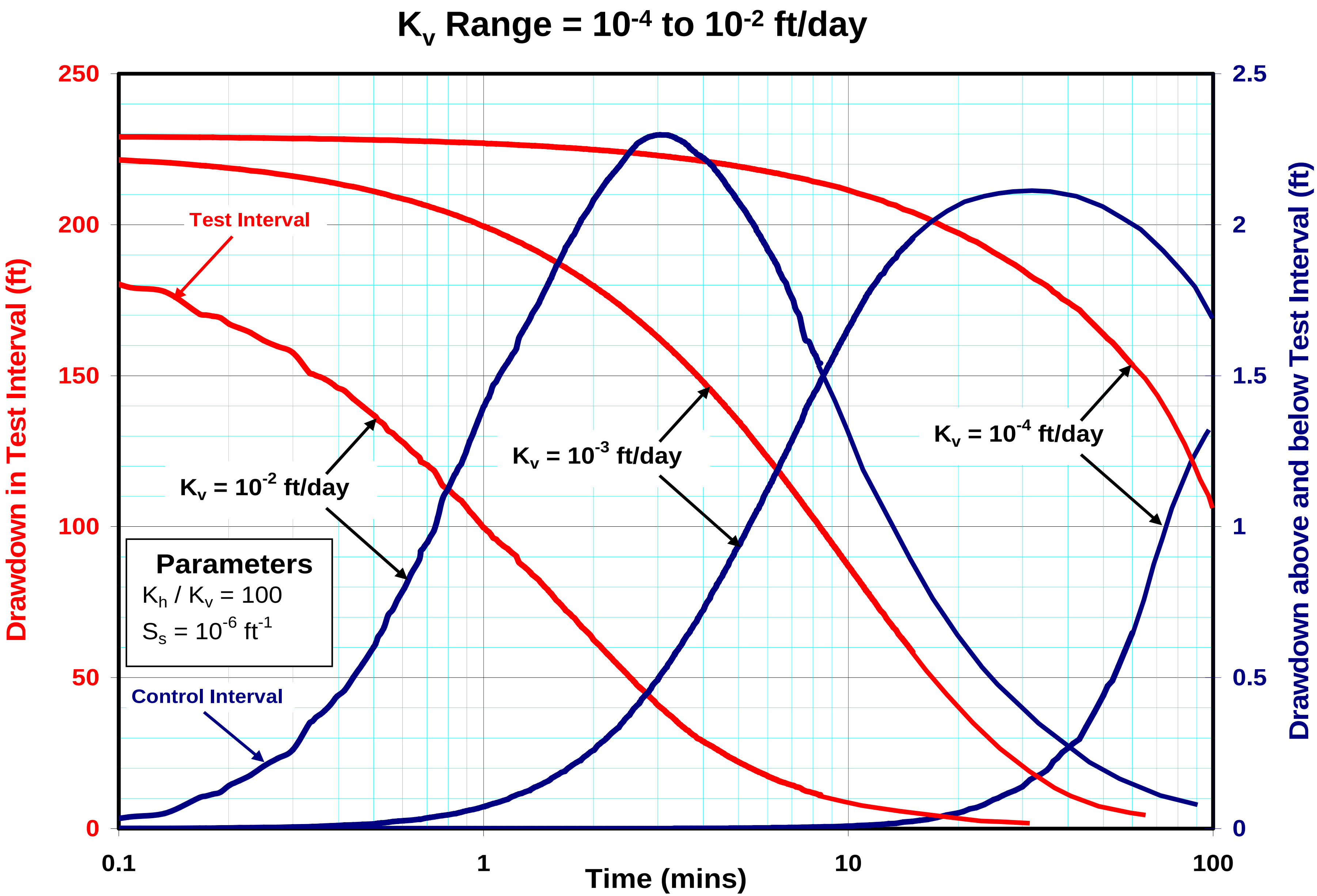
Negative Skin (Enhancement)

Packer-Buildup Test

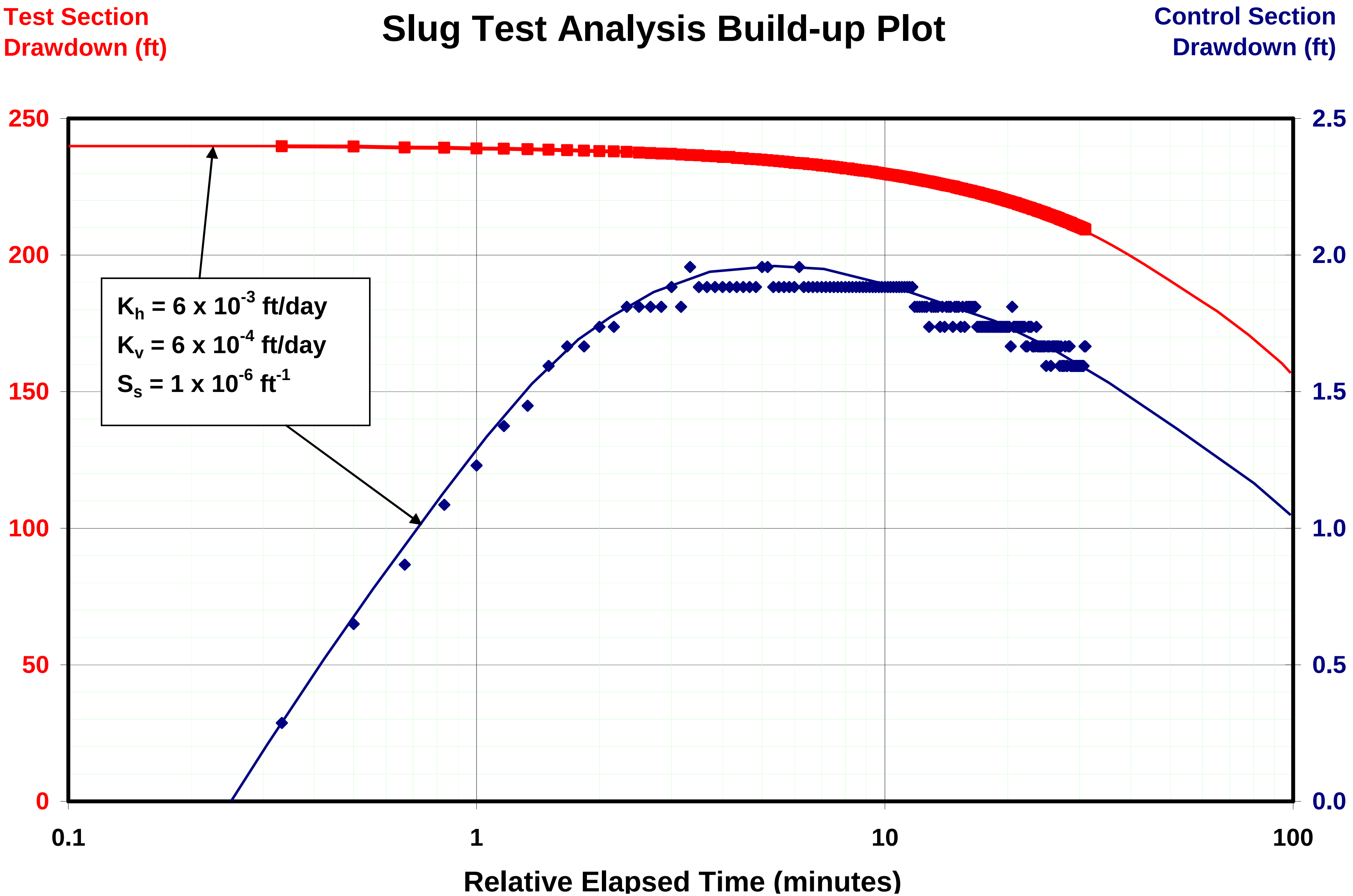
- **Inflatable Packers**
  - Three packers isolate two sections within bore hole – “test” and “control” sections
  - Inflated bladder length = 2.5 ft
- **Pressure Transducers**
  - Four transducers measure pressure response above and below each packer
  - Pressure response within two isolated sections
- **Test Method**
  - Nitrogen to establish pre-test pressure differential in test section (~100 psi)
  - Instantaneous pressure release
  - Pressure build-up in test section
  - Pressure response in control section
  - K_h measured in “test” interval (7.5 ft)
  - K_v measured across middle packer interval (2.5 ft)



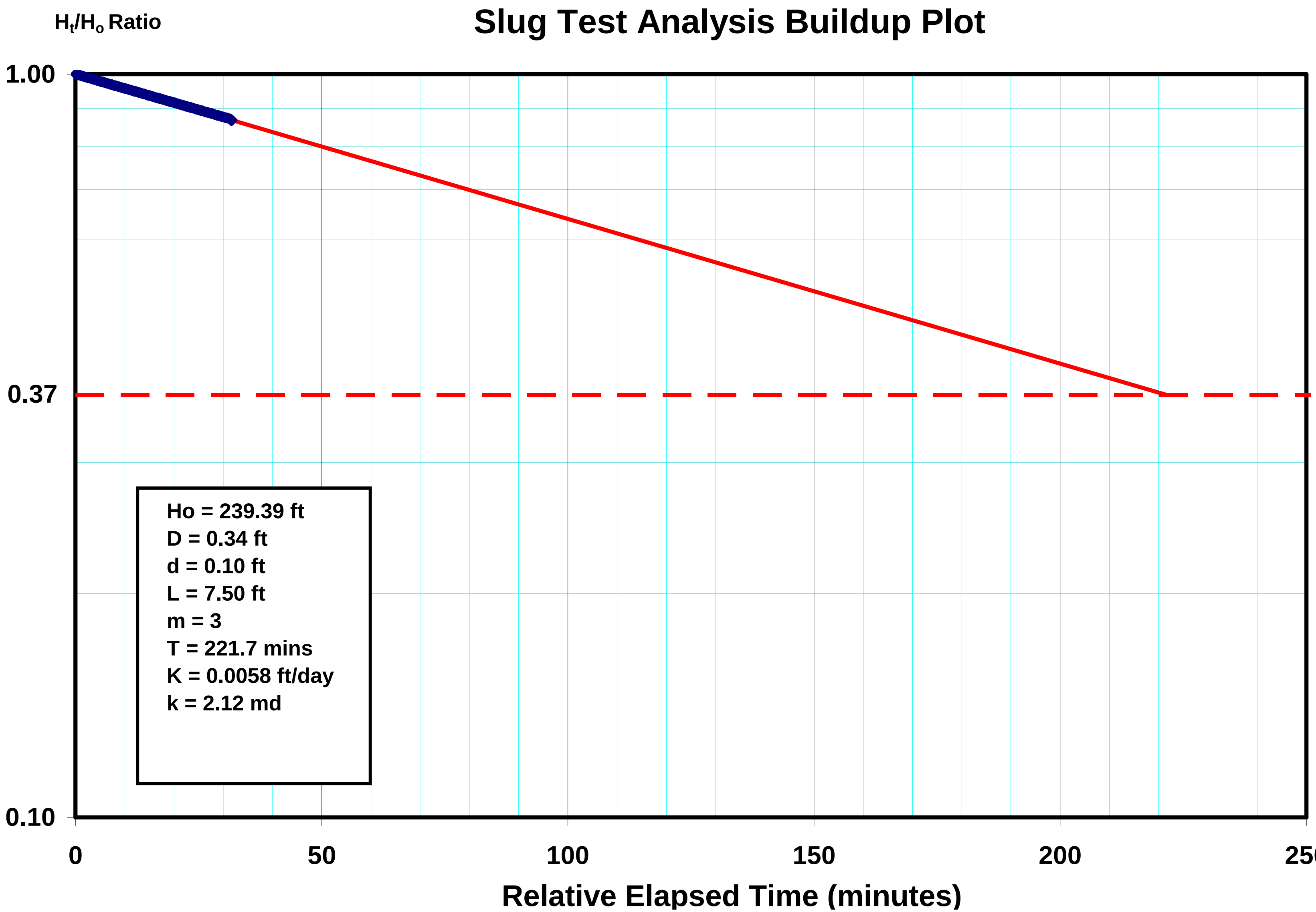
Packer-Buildup Type Curves



Example Packer Buildup Test

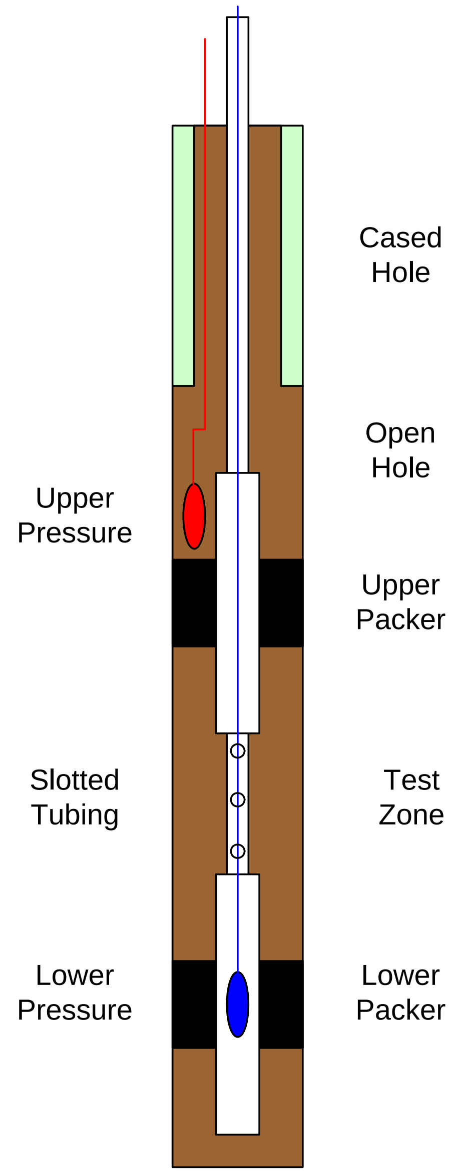


Packer Build-up Test – Hvorslev Analysis

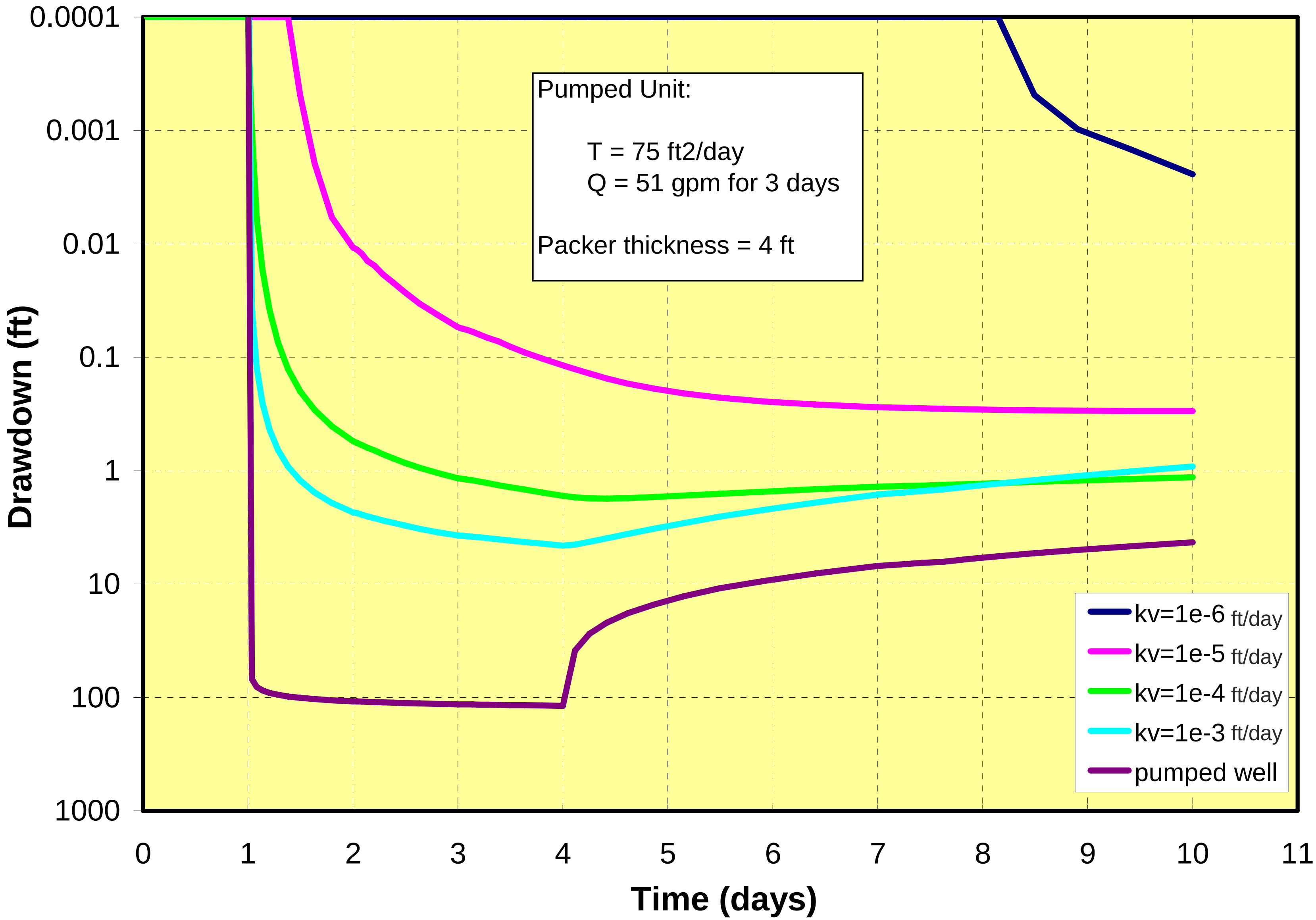


Packer-Pumping Test in Open Bore Hole

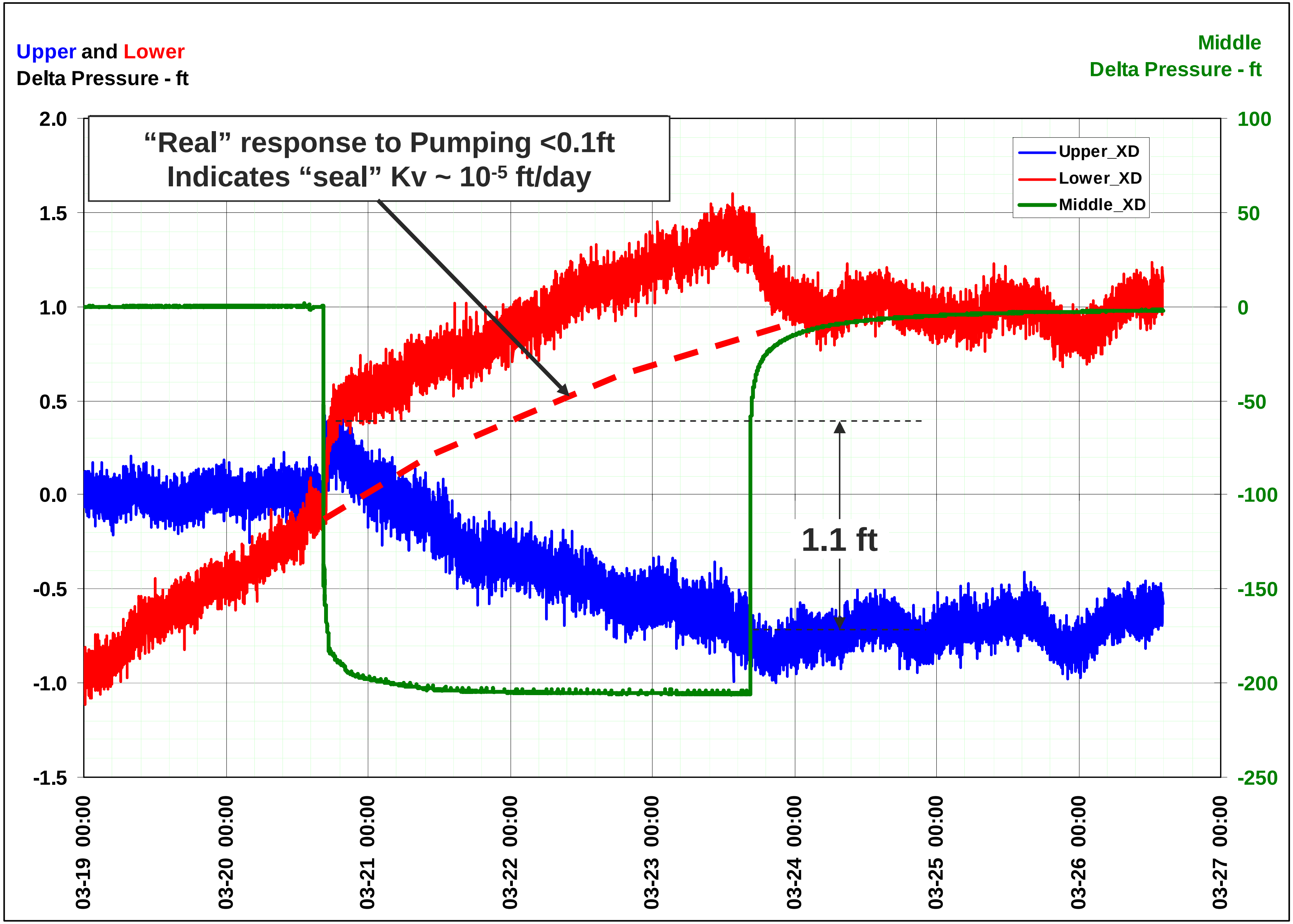
- Two packers are used to isolate transmissive zone
- Packers are inflated and pressures allowed to stabilize
- Test zone pumped for three days
- Zones above and below test zone monitored for pressure response
- Magnitude of response yields vertical hydraulic conductivity



Response across Packed-off Interval

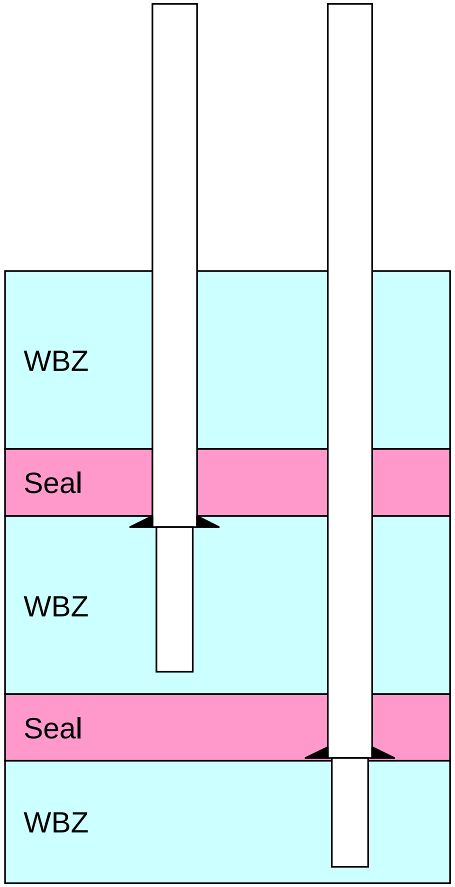


Example of Packer-Pumping Test

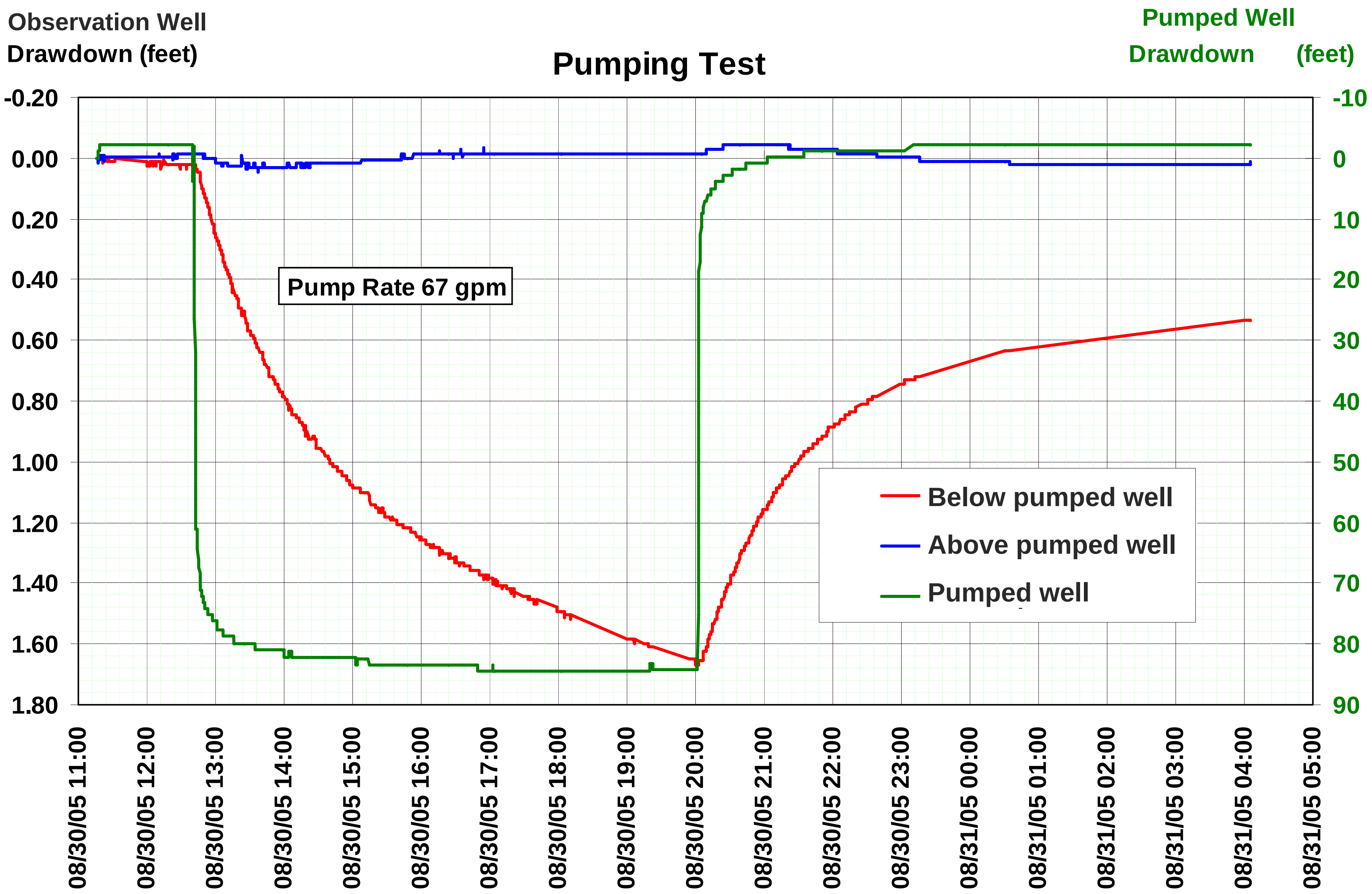


Clustered Well Pumping Test

- Two wells completed in adjacent transmissive zones (see figure right)
- Pump one well for one to three days
- Well(s) above and/or below pumped zone monitored for pressure response
- Magnitude of response yields vertical hydraulic conductivity



Example of Cluster Well Pumping Test



Conclusions

- **Vertical response testing successfully used to quantify the vertical hydraulic conductivity of oil shale intervals**
- **Longer-term tests (1 to 3 days) to quantify K_v for thick, low permeability intervals and confirm lateral continuity**
- **Shorter-term (~1 hr) packer tests used to quantify K_v of thin (~2.5 ft) intervals and allow more rapid identification of potential containment units**