FIELD TRIALS OF PERIODIC-SINUSOIDAL SLUG TESTS FOR AQUIFER PROPERTIES AND LNAPL TRANSMISSIVITY

Don A. Lundy, PhD, PG – GES, Tucson, AZ
David Demko, PG and Greg Rosenzweig, PG – GES, Exton, PA

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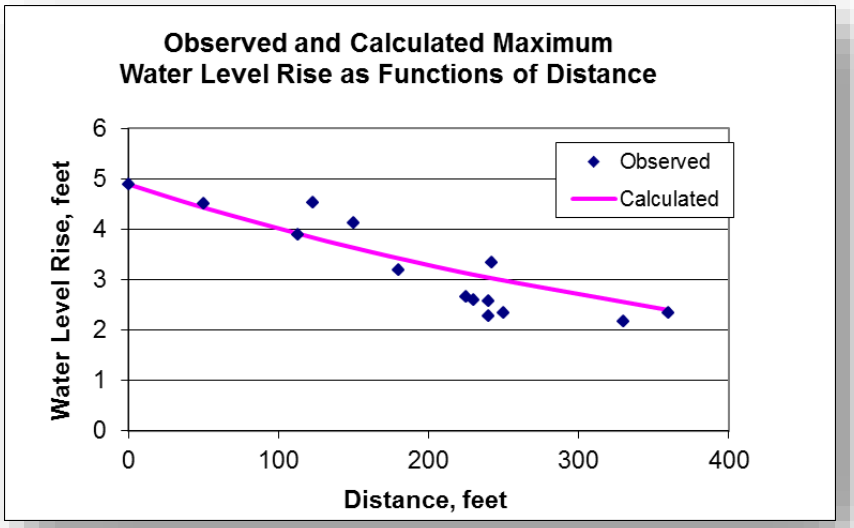
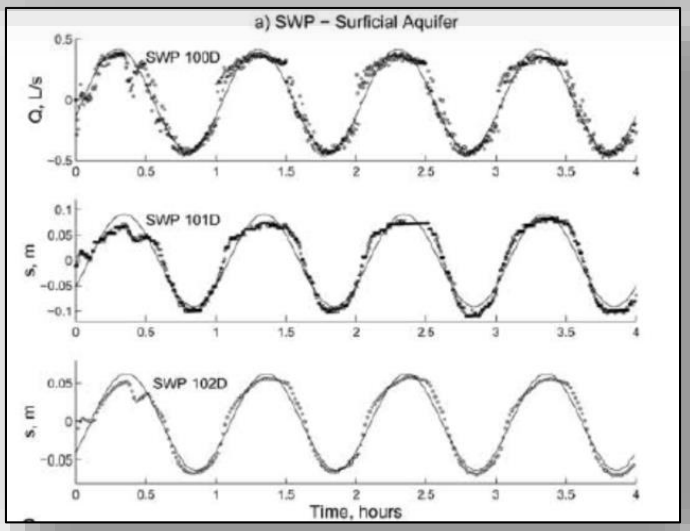
Sinusoidal Aquifer Tests Are Not New

- Tidal fluctuations
  - > Shoreline is line source
  - > Wave amplitude and lag time used to estimate hydraulic diffusivity (T/S) (Ferris, 1951)
- Sinusoidal pumping
  - > Pumping and injecting water at sinusoidal rates
  - > Analytical soln. to estimate aquifer parameters (T & S) Rasmussen, Haborak, and Young (2003)



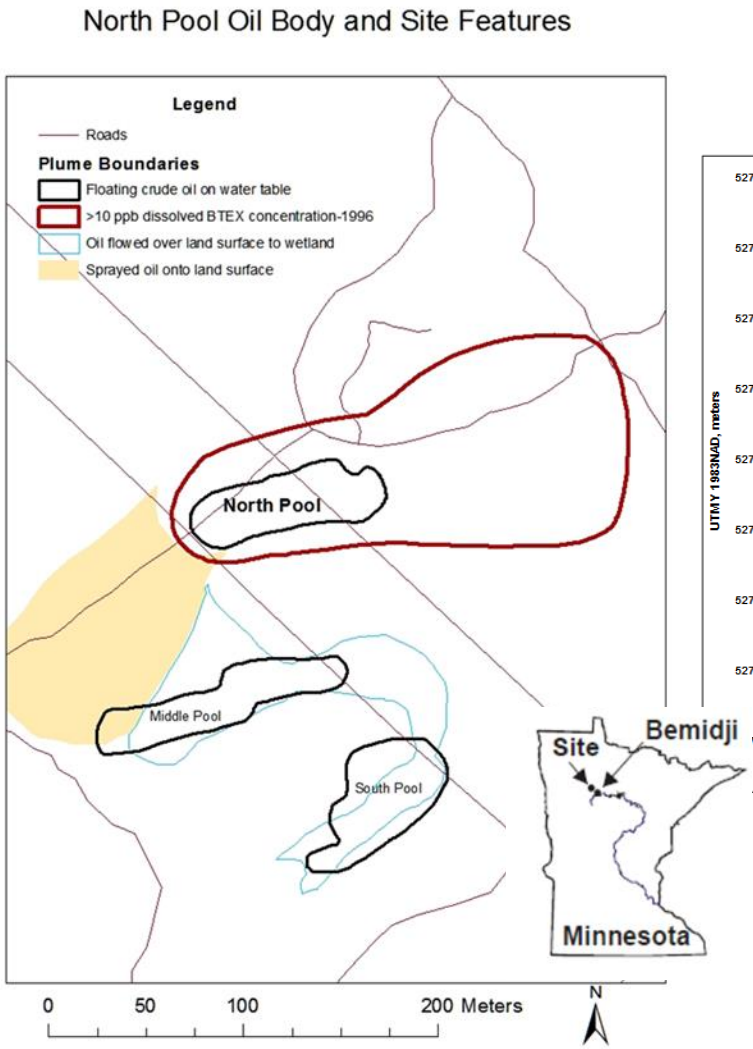


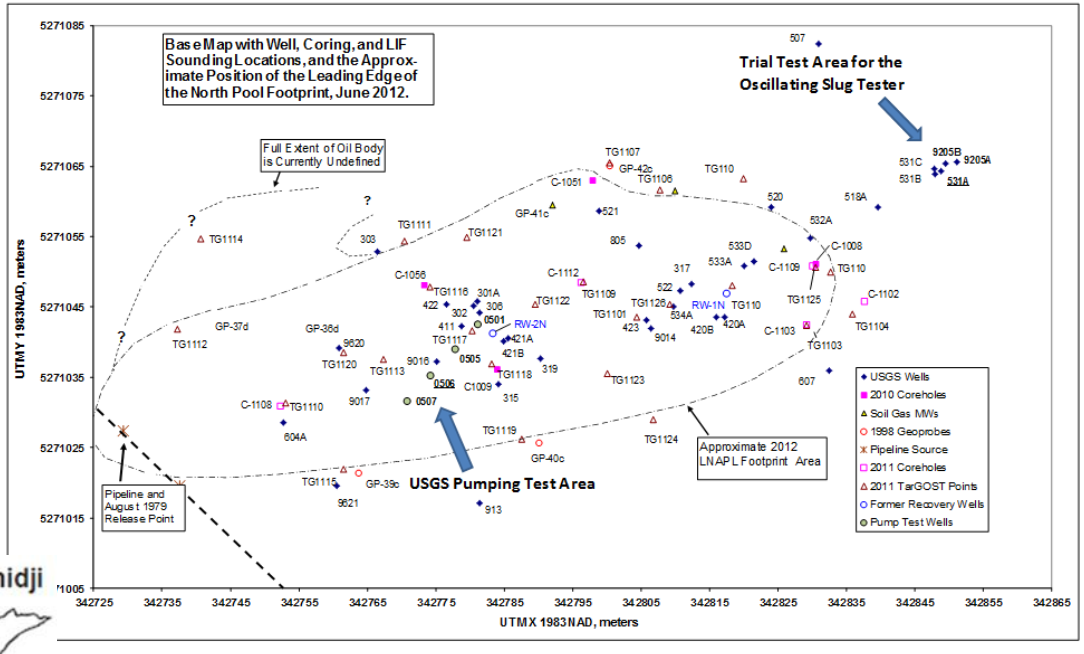
Technology Development and Benefits

- Development Steps
  - > Funding
  - > Design and construction
  - > Field trial testing/analysis
  - > Validation of results
    - Groundwater pumping tests
    - LNAPL transmissivity tests
- Benefits: Less Time & Money
  - > No water storage/treatment
  - > No discharge permitting
  - > Shorter test duration
  - > Two fluid parameters, one test

First Trial Test in Glacial Aquifer

USGS Crude Oil Release Research Site, Bemidji, MN



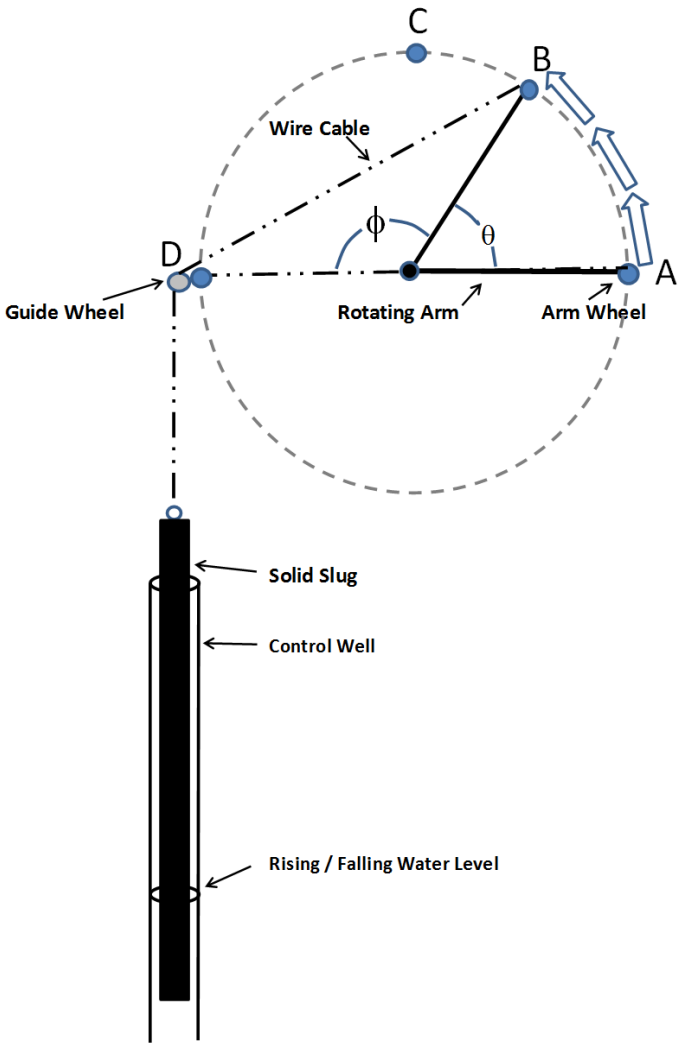


Source: Lundy, 2014

Field Test Equipment Set-up

Slug Movement to Pumping/Injection Rates

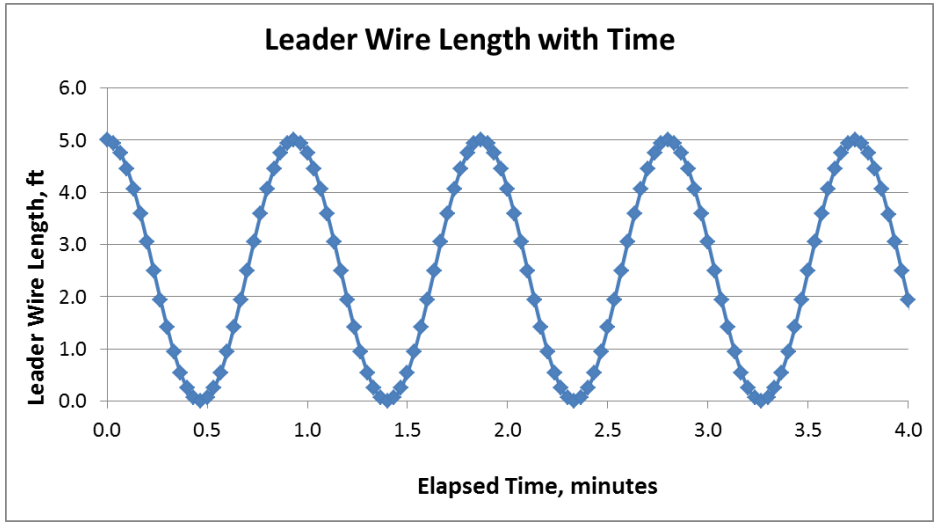
- Arm rotation moves slug
- Insertion = Injection
- Withdrawal = Pumping
- Constant angular velocity
- Equal θ change per time step
- Wire cable length change is sinusoidal
- Q rates based on slug length change with time

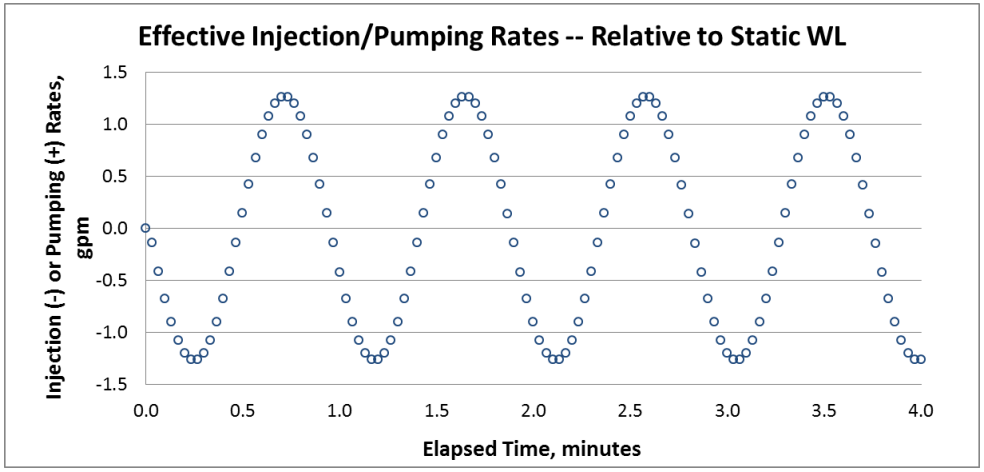


Source: Lundy, 2014

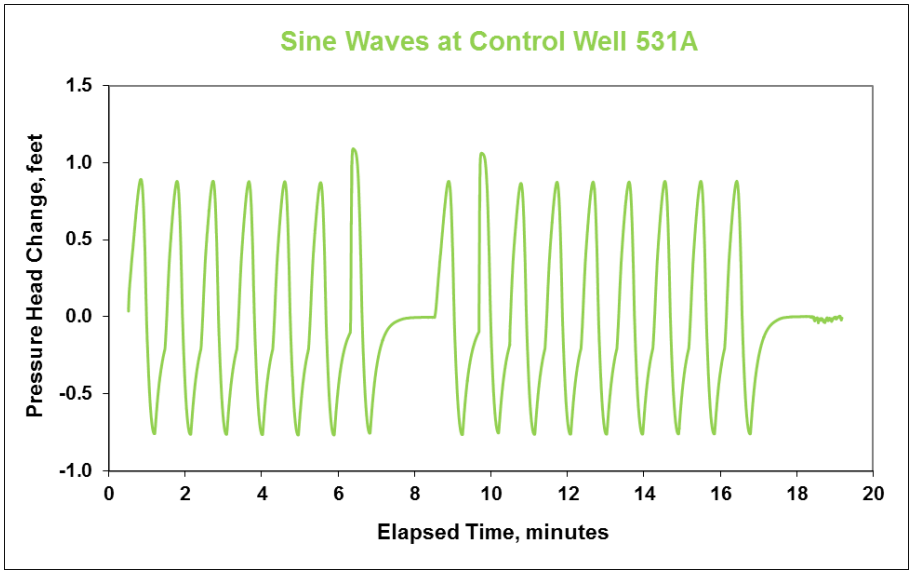
Calculating Pumping/Injection Rates

- Model slug movement
- Calculate changes in leader wire length
- Known: slug length and diameter
- Changes in cylindrical volume/time = Q-rates



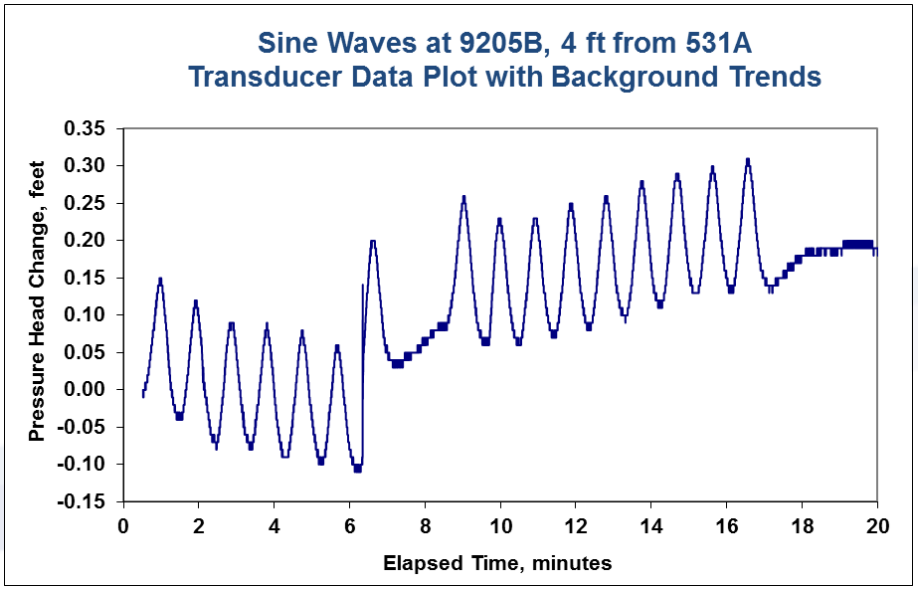


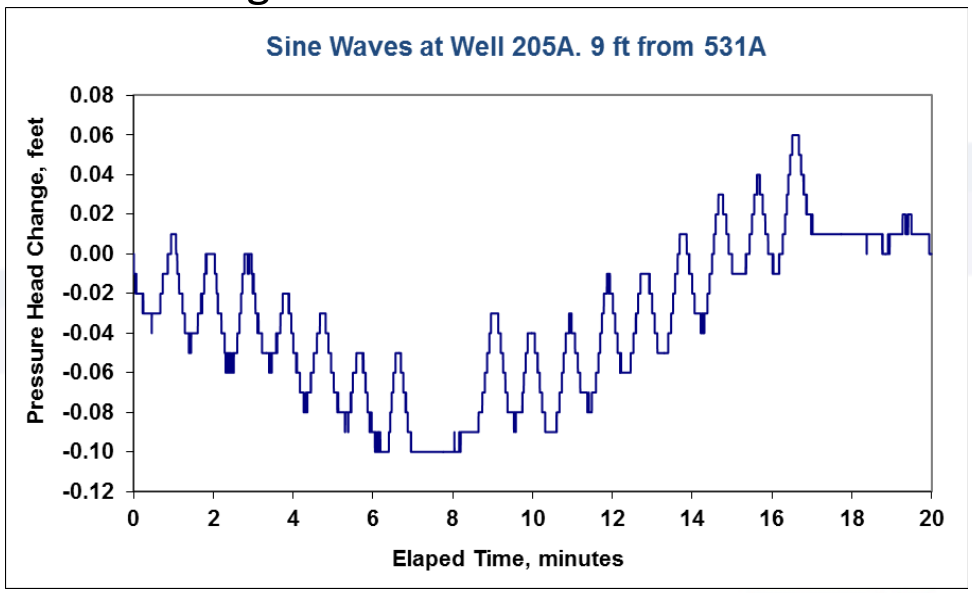
Transducer Responses – First Trial Test



Observations:

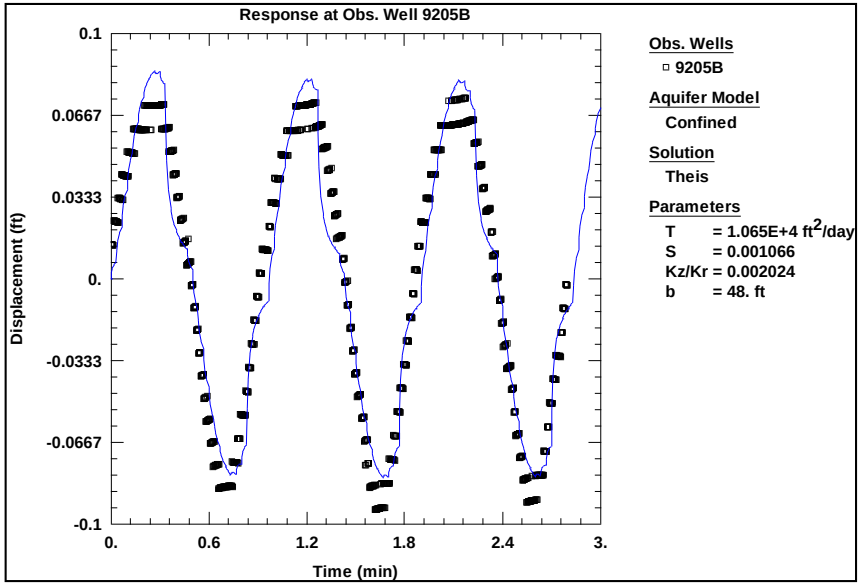
- Sine waves at control well propagate to obs. wells
- Amplitudes diminish with distance.
- Lag time for wave arrival is small
- Unconfined aquifer behaves as confined in early time
- Signal must be filtered from background noise



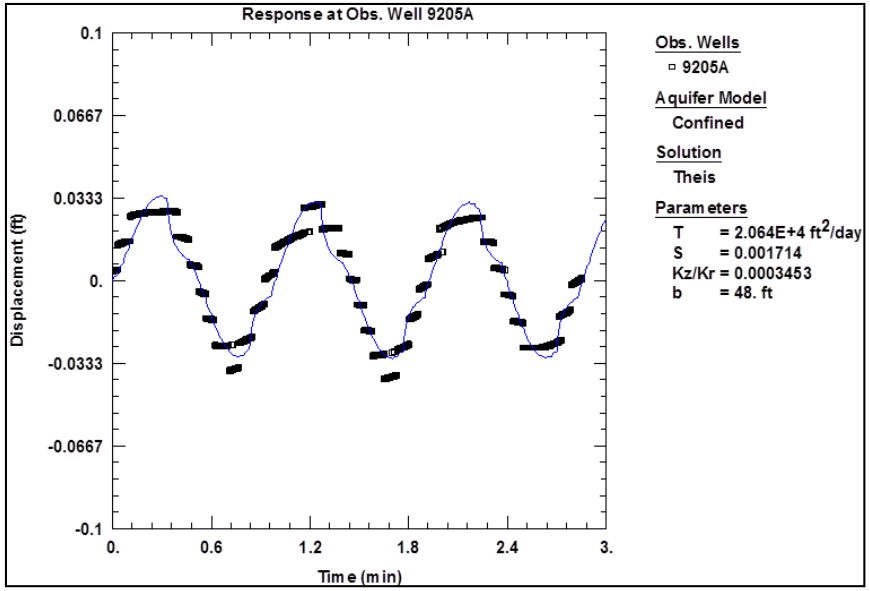


Data Analysis of Filtered Aquifer Response

Nearest Observation Well

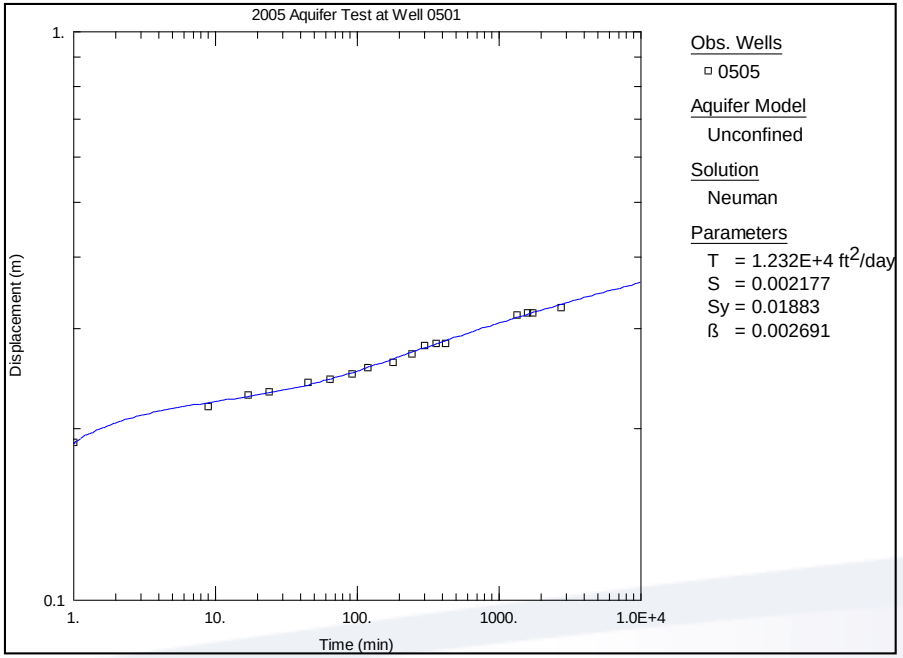


Furthest Observation Well



Comparison to a USGS 45-hr Pumping Test

- Sinusoidal Slugger
  - > Average trans. = 14,810 ft^2/d
  - > Average storativity = 1.56E-03
- Conventional Pumping
  - > Average trans. = 13,425 ft^2/d
  - > Average storativity = 1.84E-03
- Results
  - > Average trans. within ~10%
  - > Average storage within ~16%
- Valid for estimating aquifer properties



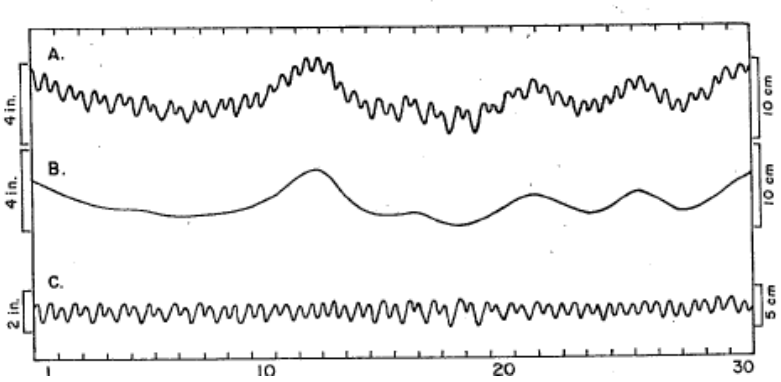
2cd Trial – Karstic Limestone Aquifer with LNAPL

- Outcrop with Fractures

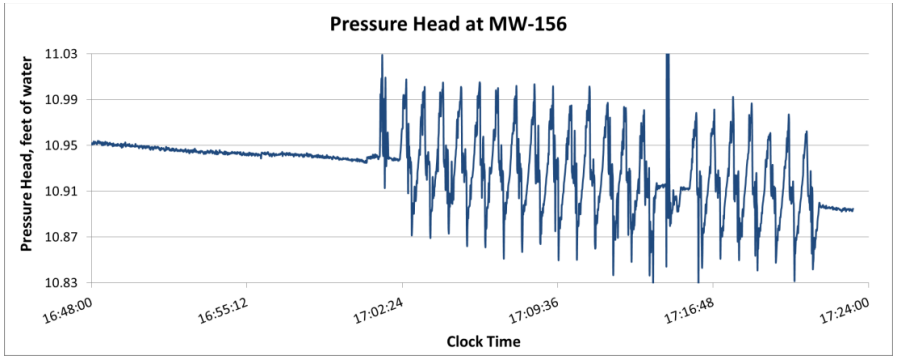
- Core with Dissolution Features

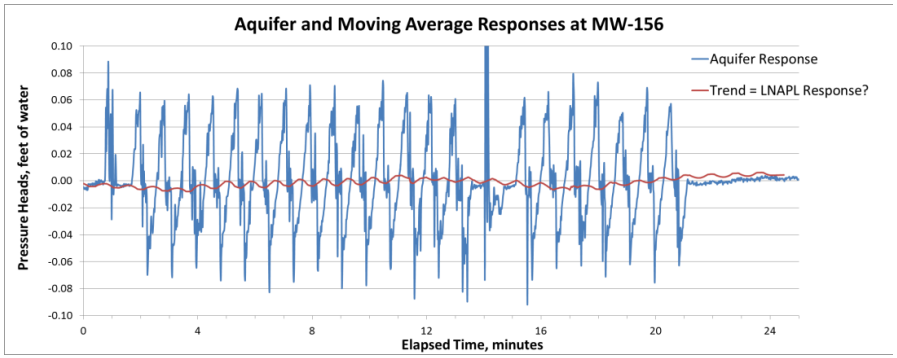
Aquifer Test Analysis in Tidal Environment

- Separate *signal from noise*, the tidal trend
  - > Subtract *moving average heads* from *total heads* to get the *residual heads*
  - > *A* – *B* = *C* below, where
    - ***A*** = Total transducer head
      B = Moving average head (trend)



- Separation at a slugger test control well
- Trend has LNAPL response?

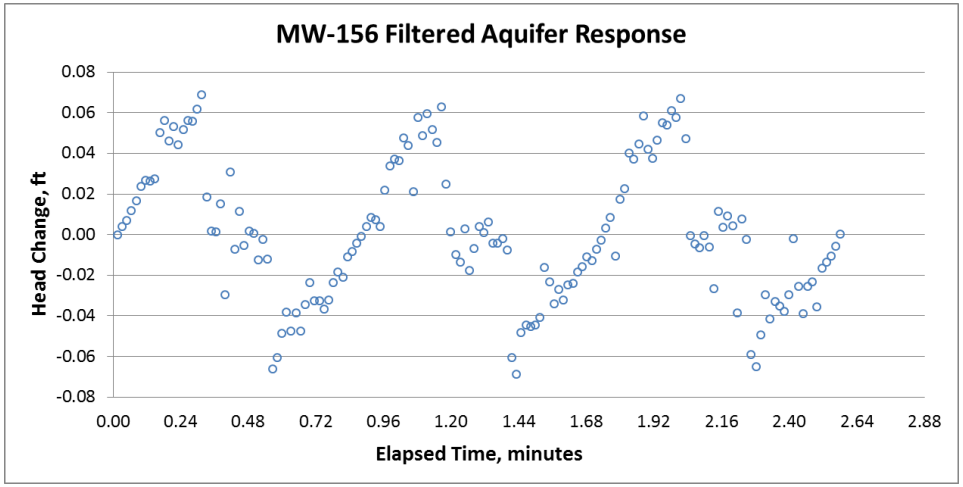




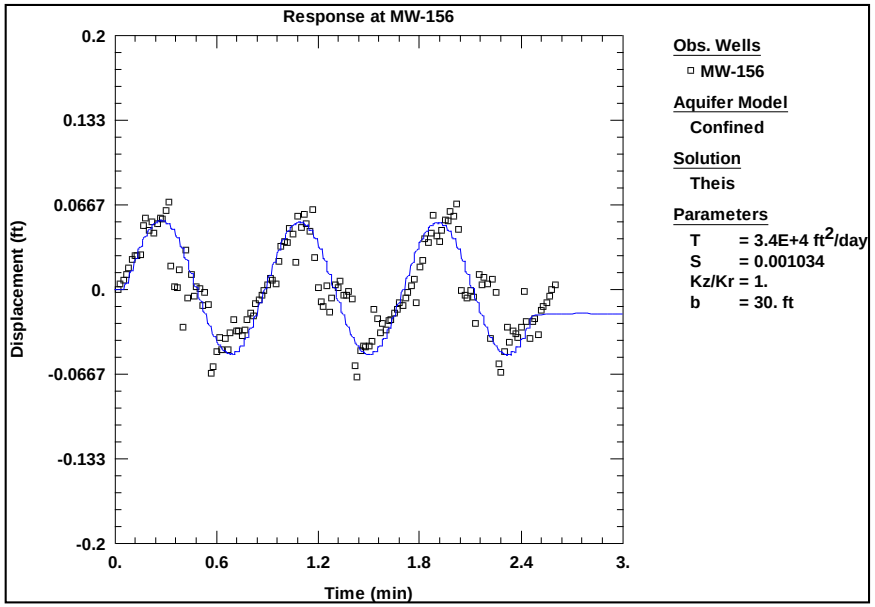
Source: Vacher, 1978

Aquifer Response Analysis

- Select three consecutive slugger sine waves.
- The *least influenced* by background noise.

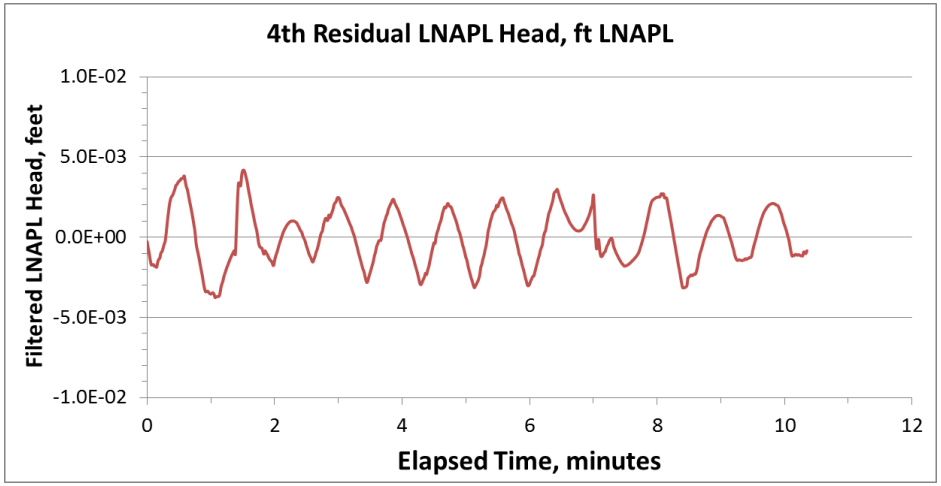


- Analysis with software
- Transmissivity agrees with published values

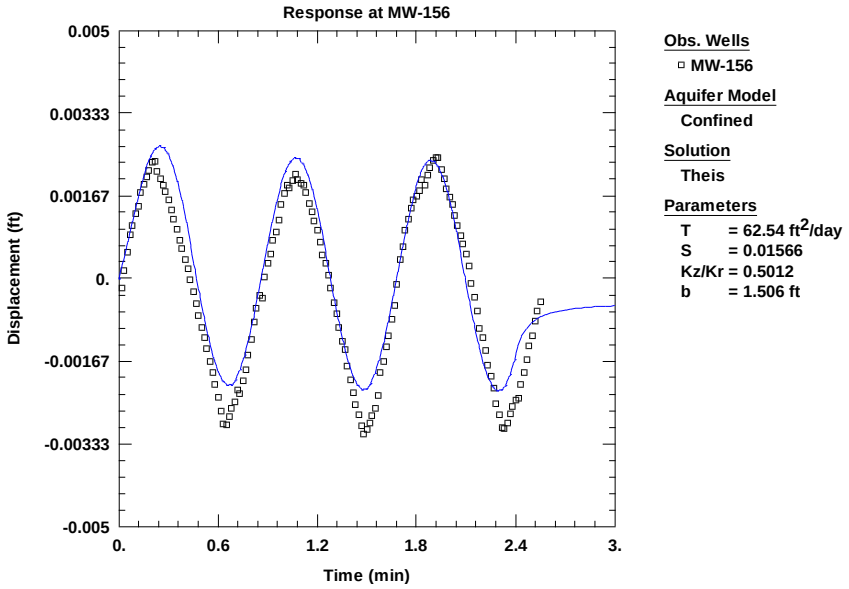


Refine LNAPL Response and Analyze For T_{LNAPL}

- Filter the previous LNAPL response trend(s)
  - > Calculate moving average of previous trend and subtract it from that trend
  - > Repeat this as needed
- After four filtering steps:



- Adjust the calculated sinusoidal pumping rates
  - > Analyze with AQTESOLV or equivalent
  - > Repeat until calculated and observed responses agree



Testing the LNAPL Hypothesis with Other Results

- Sinusoidal test at MW-156
  - > $T_{aquifer} = 3.4 \times 10^4$ ft^2/day
  - > $T_{LNAPL} = 65$ ft^2/day
- Baildown test results at nearest MW (8 ft away)
  - > $T_{LNAPL} = 10$ ft^2/day
- Range of five baildown tests
  - > $T_{LNAPL} = 10$ to 440 ft^2/day
- *Caveat*: Unconfined T_{LNAPL} *vary with tide fluctuations*.
- The scale effect of transmissivity is well supported onsite by
  - > Slug tests
  - > Pumping tests
  - > Large-scale tidal response tests.
- Sinusoidal tests are expected to provide larger transmissivities than slug/baildown tests.

Conclusions Regarding Trial Sinusoidal Tests

- Provide aquifer transmissivities comparable to conventional pumping tests reported by others at two sites.
- The aquifer sine wave signals can be filtered from background tidal noise for analysis with commercial software.
- When LNAPL is present, multiple filtering steps on residuals can produce low amplitude sine waves timed with the water table sine waves.
- When analyzed with best-fit LNAPL pumping/injecting rates, these provide LNAPL transmissivities in the range of baildown tests on one test site (which can vary with tidal fluctuations).
- Further testing of the LNAPL transmissivity application method is recommended on other sites to provide more confidence in the methods used here.

Thank you.