Flexible Infiltration Test Methods for Evaluating Infiltration Feasibility

Infiltration Study
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Partners and Disclaimers

- City of Tacoma – Merita Trohimovich (sponsor and field support)

- Dept of Ecology – Justin Donahue (grant manager)

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Objectives

- Expand the infiltration testing toolbox
- Provide methods for estimating deep drywell capacity
- Provide technical basis for correction factors

- Demonstrate how hydraulic conductivity (K) can be used to estimate the infiltration rate and/or capacity of any size and shape of infiltration facility

Study Tasks

- Numerical Validation of Testing Methodologies
- Field Validation of Infiltration Testing Methods
- Evaluation of Layering, Perching, and Groundwater Mounding
- Infiltration Guide

Saturated Hydraulic Conductivity (K_s)

- Used to describe homogeneous and isotropic soil layers
- Calibration provides K_s since methods assume homogeneous and isotropic stratigraphy

Bulk Hydraulic Conductivity (K_b)

- Incorporates layering and/or shallow groundwater
- Field testing provides K_b
- Simulation results of layered stratigraphy and/or shallow groundwater provides K_b

Design Hydraulic Conductivity (K_d)

- After correction factors are applied
- Used in hydrologic modeling to size facilities

Skip Over Lots of Technical Detail

- Developed soil sorption number ($\alpha*$) for 10 soils types typical of soils in Washington State
- Conduct >400 calibration simulations to develop shape factors for cased and uncased scenarios
- Calibration scenarios had a maximum error of 13% and average error of 4%
- Conducted shallow and deep infiltration testing to evaluate field feasibility and variability

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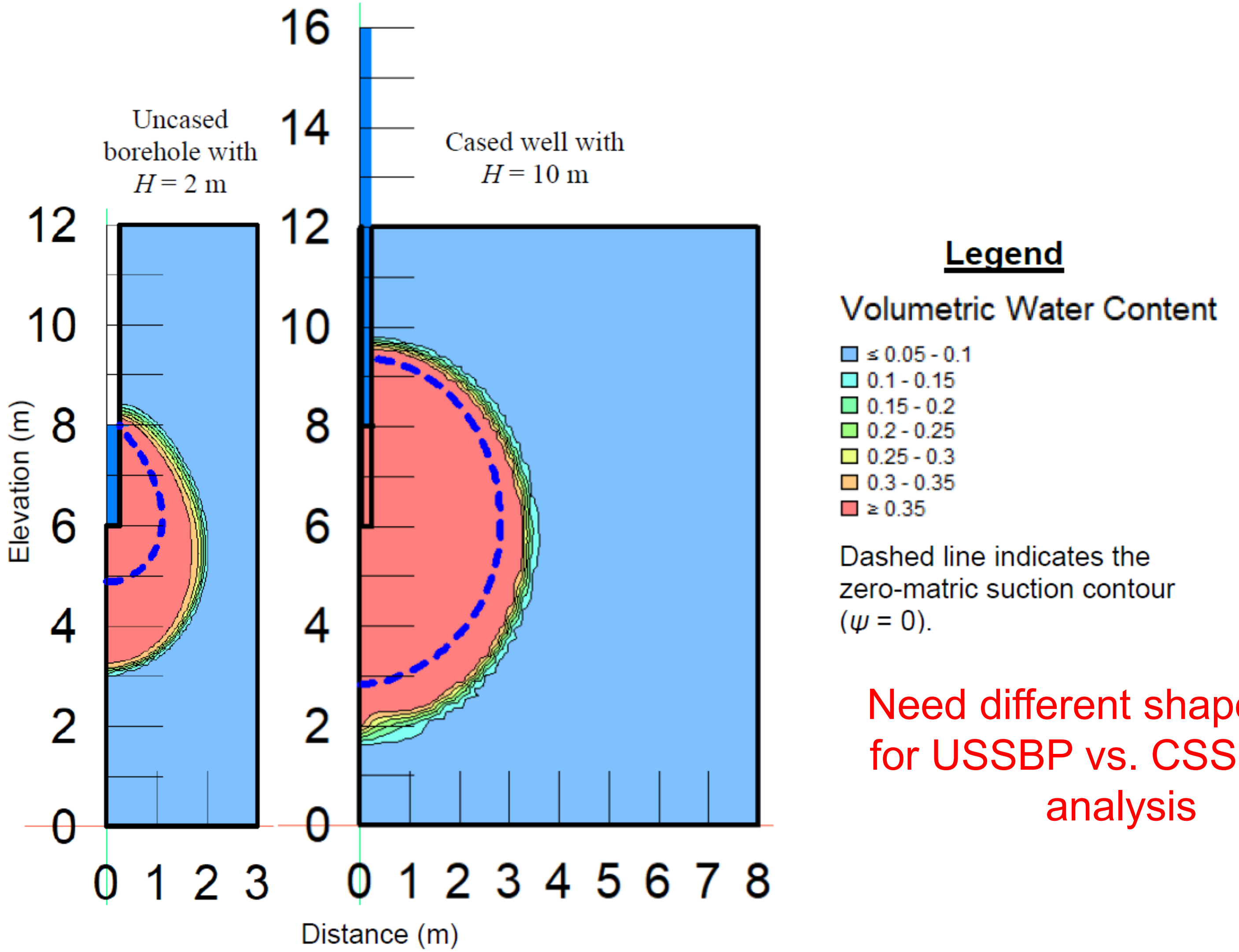
Comparison of USSBP (Uncased) vs. CSSBP (Cased) Results Assuming Screen Length (L) = 2 m



Need different shape factor for USSBP vs. CSSBP test analysis

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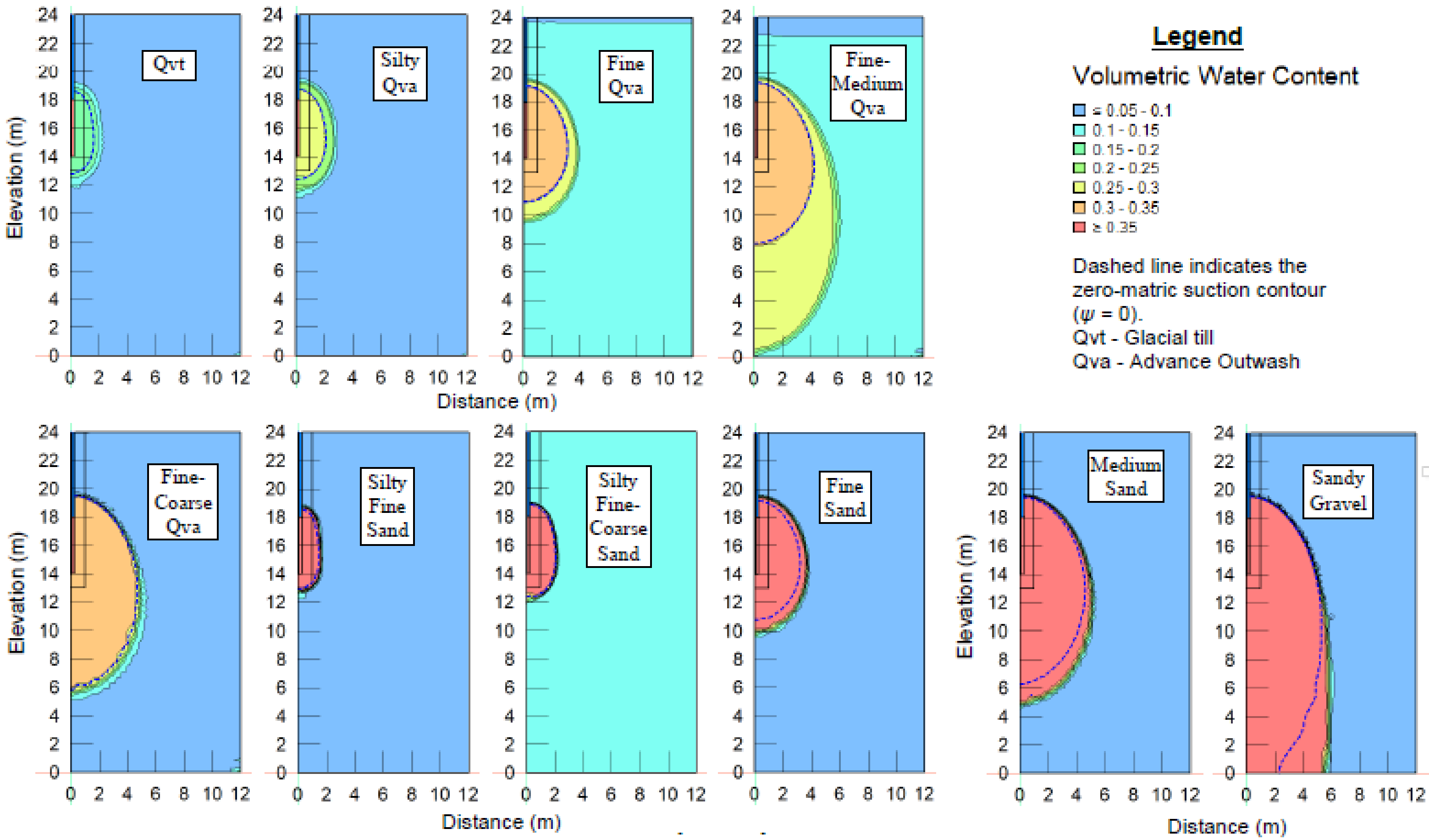
CSSBP Results for Test Well after 6 Hours

L = 4 m and *H* = 10 m



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Test Pit Excavation and Testing

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Shallow Borehole Construction

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Shallow Borehole Testing

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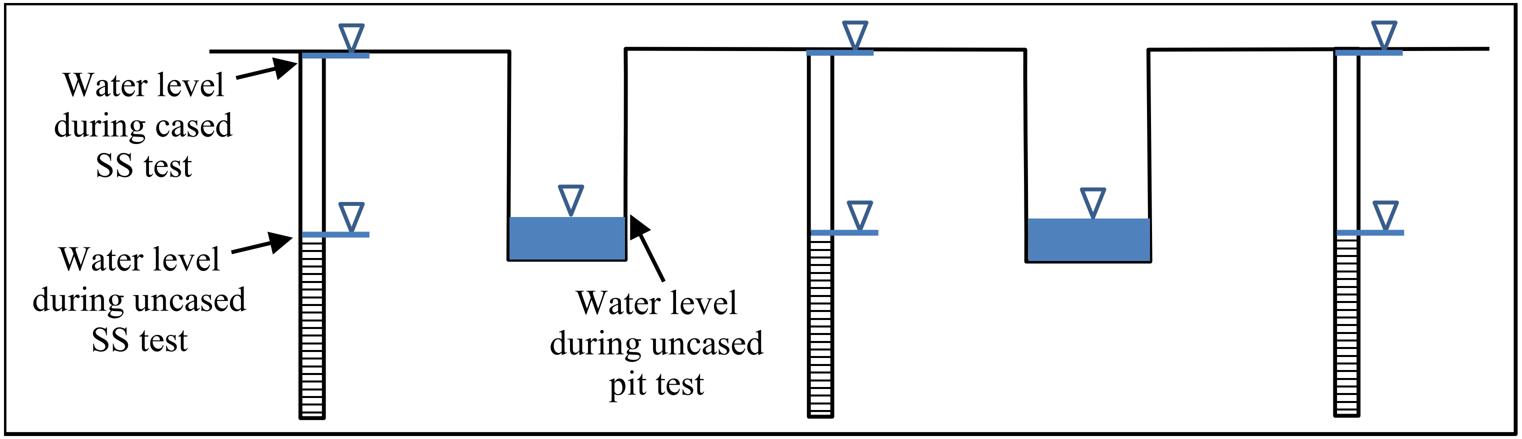
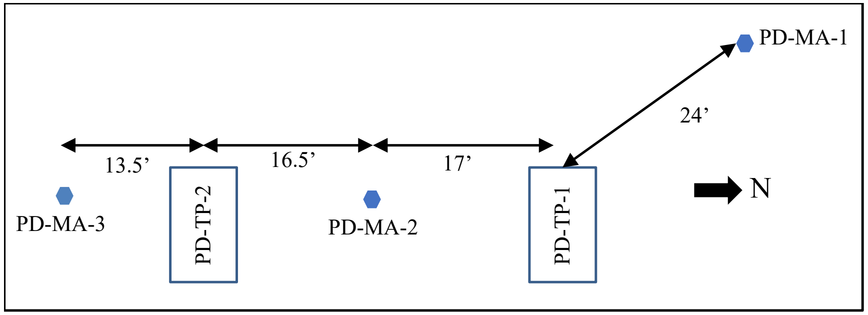
Shallow Test Configuration Cross-Section

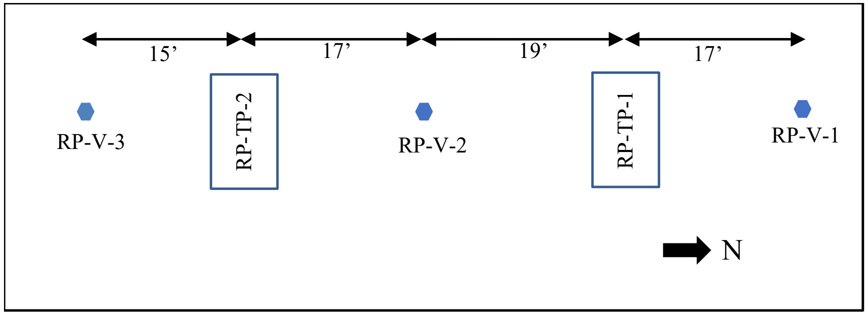


Test Configurations

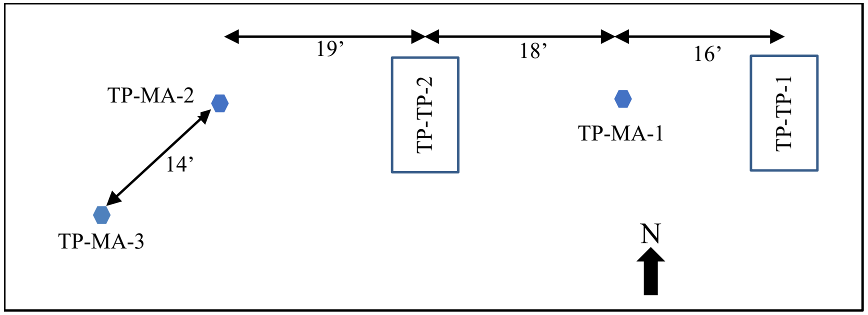
Point Defiance Elementary (glacial till)



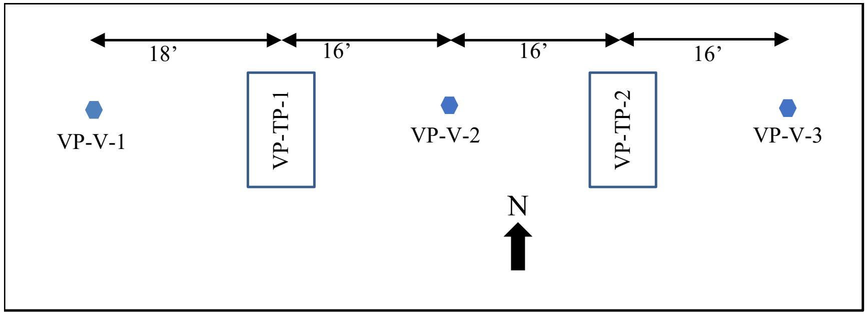
Roosevelt Park (recessional outwash)



Tacoma Power (fill)



Verlo Playfield (advance outwash)



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Conclusions From Shallow Testing

- Vactor truck provides cleaner hole and faster drilling in gravels than auger drilling
- High degree of K_b variability over short distances, median variability factor of 1.8
- Shallow borehole tests overestimated test pit K_b, median variability factor of 1.9
- CSSBP K_b generally higher than USSBP K_b in same test well, median variability factor of 1.7
- If using well tests to size horizontal facilities, use USSBP method

Note: Variability Factor = $\frac{\text{Higher } K_b}{\text{Lower } K_b}$ equals 1 when no difference

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Deep Infiltration Field Testing

- 8 wells, all previously installed for other projects
- All glacially over-consolidated sandy soils treated as advance outwash
- 7 wells drilled using Sonic drilling (uses double casing)
- 1 well drilled using hollow stem auger
- 18-30 ft of sandpack
- Cased steady-state performed the day after uncased steady-state

Deep Infiltration Testing

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Conclusions From Deep Testing

- Need to extend drop casing below water table to eliminate air entrainment during high flowrate borehole tests and in production drywells
- Hollow stem auger wells not recommended for infiltration testing, Sonic drilling and air-rotary are recommended
- CSSBP K_b generally higher than USSBP K_b, median variability factor of 1.15, highest factor was 1.8

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Numerical Simulations of Layering and Mounding

- Evaluate impact of layering and mounding
- Evaluate/explain field test results
- Combined with field results, provide basis for correction factors used to estimate K_d

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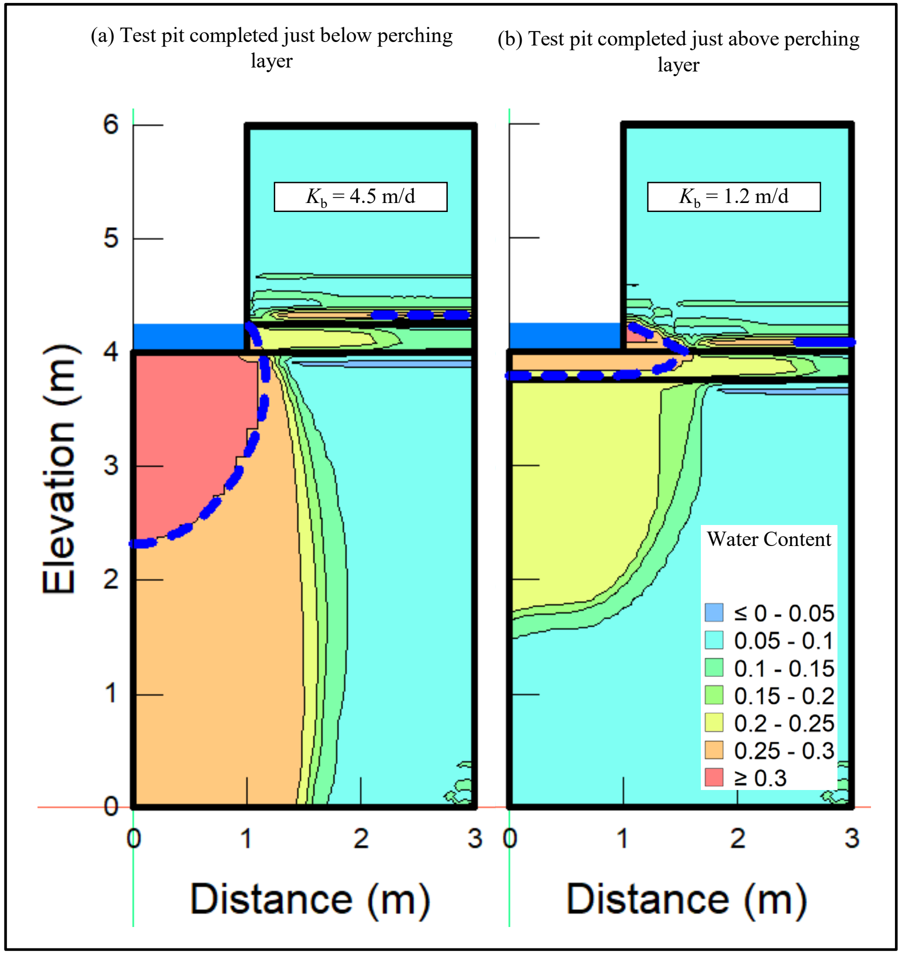
Test Pit Results Very Sensitive to Elevation of Pit Bottom



Fine-Coase Qva (K_s = 5.0 m/d) with a perching layer of silty Qva (K_s = 0.5 m/d)

Extending test pit below perching layer increases K_b by a factor of almost 4

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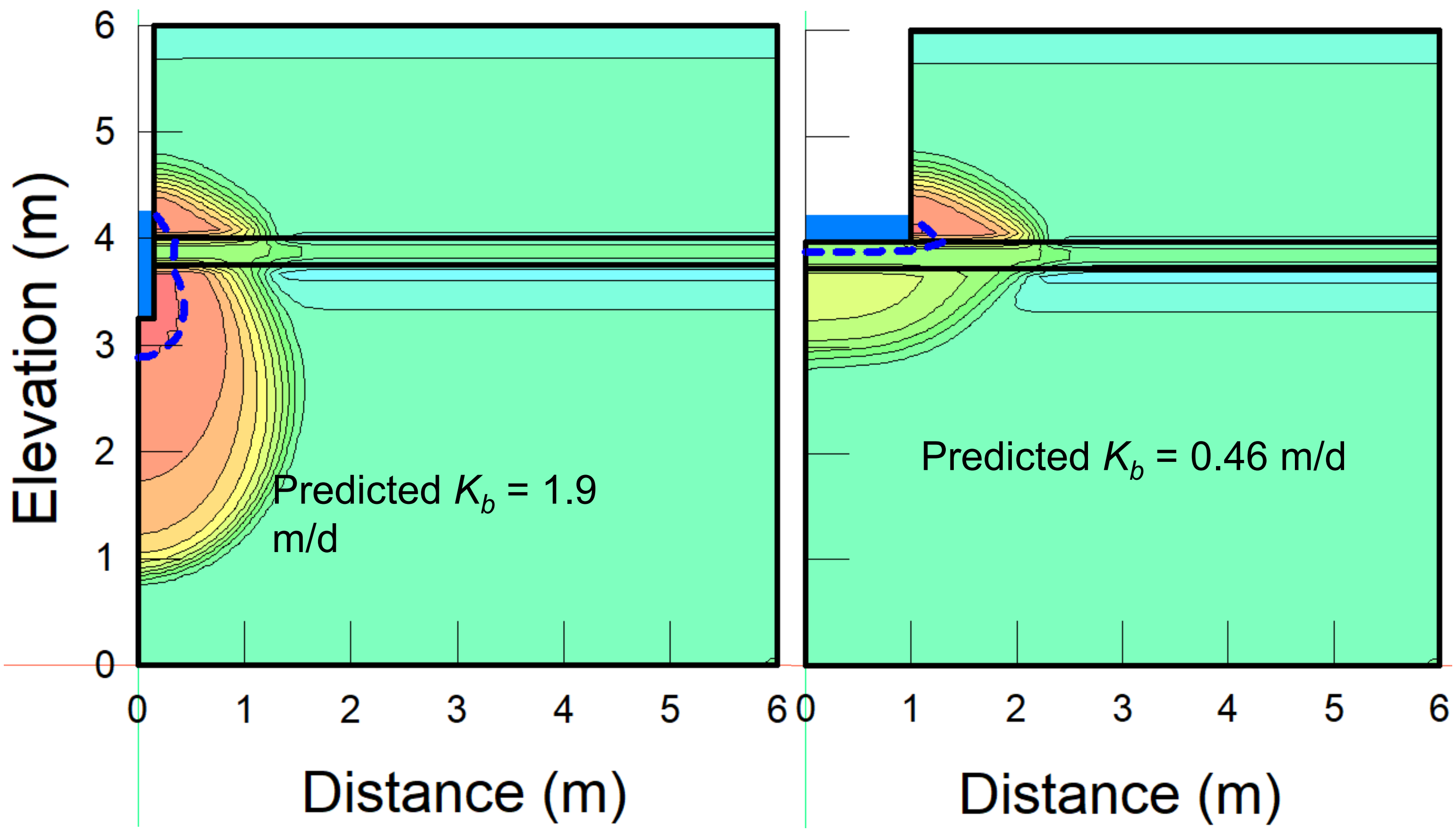
Borehole Below Bottom of Test Pit can Over-Estimate Pit K_b (Layer at Bottom of Pit)



Test well extends below perching layer, providing 4-fold higher estimate of K_b (actual K_s = 2.0 m/d).

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General Conclusions from Layering and Mounding Simulations

- 6-hr tests are good at picking up perching layers and groundwater as deep as 3 m for permeable soils
- K_b results can vary significantly based on vertical location of perching layers relative to test facility
- When using well tests to size horizontal facilities test interval should be short (about 3 ft)
- Generally, not achieving steady state by the end of 6 hours is a good indication that perching or groundwater mounding is occurring
- For small sites, groundwater mounding can be addressed using a correction factor
- For large sites (>10,000 sf of hard surface?) groundwater mounding analysis may be warranted

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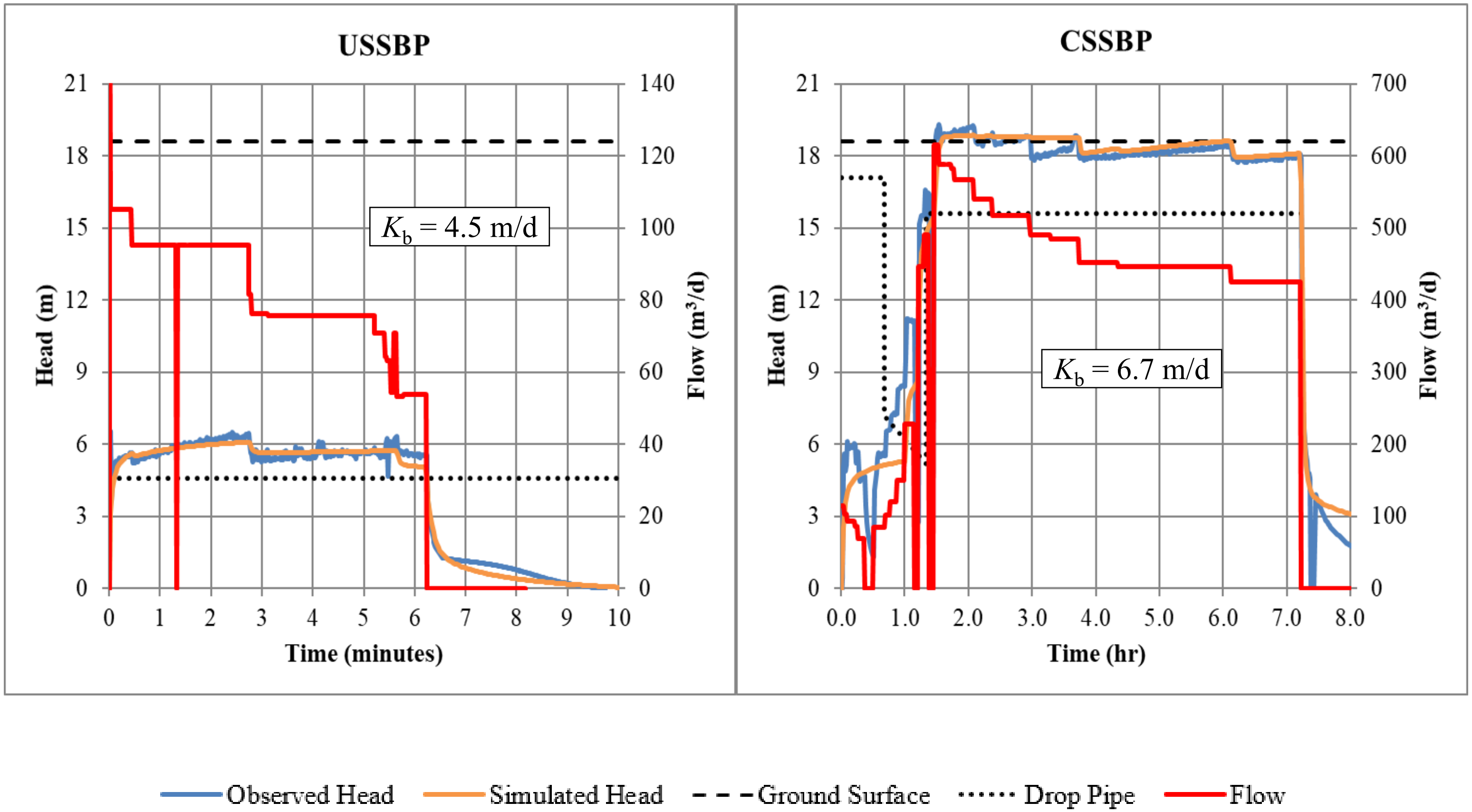
Numerical Matching of NG-B-201 Tests



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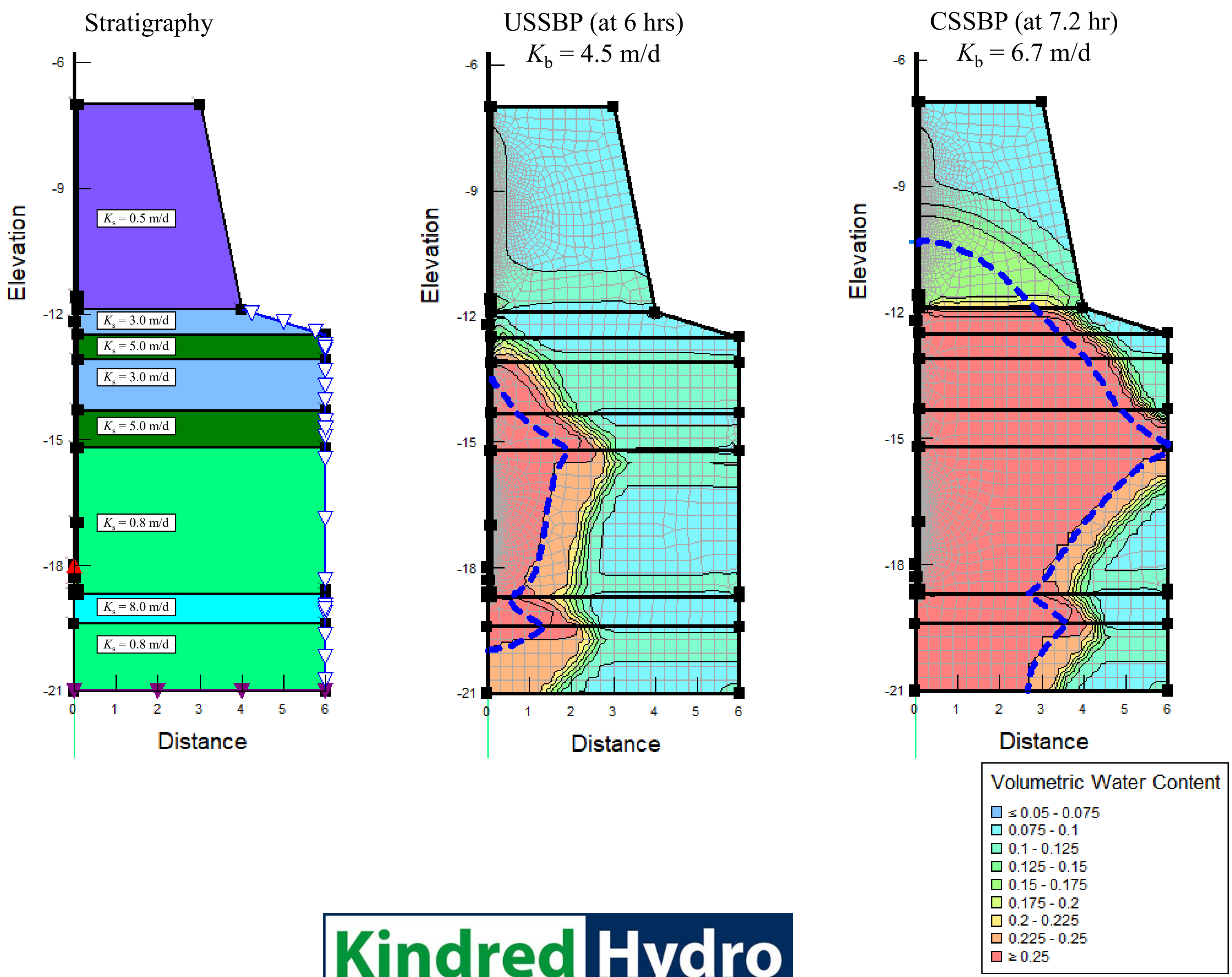
Numerical Simulations of NG-B-201 Tests



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Infiltration Guide - General Approach

- Important! Methods presented here are not fully reviewed or approved by Ecology
- Shallow infiltration based on results of 6-hour steady-state tests either in testpit or shallow test well
- Deep infiltration based on results of 6-hour steady-state test in test well screened over same interval as planned production well
- Geotech calculates K_d from K_b using appropriate correction factors
- For shallow facilities, civil engineer calculates infiltration rate using K_d and geometry of infiltration facility
- For drywells, civil engineer calculates well capacity as a function of stage (ponding head)
- Mounding analysis conducted when warranted
- We're currently soliciting feedback. See detailed field methods at end of presentation

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Field Testing

- Types of test facilities:
  - Test pit with bottom area of 16-50 sf
  - Shallow vactor or hand auger temporary test well (<10 ft deep, abandoned after test)
  - Deep test well (permitted monitoring well construction, can be >100 ft deep)
- Add water for 6 hours, monitor water level and flow rate
- USSBP recommended for shallow infiltration facility
- CSSBP recommended for deep drywells
- When feasible, characterize soil and groundwater conditions below proposed infiltration facility

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USSBP Test in Test Pit

- Excavate test pit with bottom area of 16-50 sf
- Bottom of pit should be at least 3 ft deep and at least 12 inches below surficial loose soils
- Collect soil sample from bottom of pit for grainsize analysis
- Bottom of pit should be at close as possible to base of proposed infiltration facility (± 12 inches)
- Add water for 6 hours, monitor water level with transducer and/or stadia rod
- Record flow rate during test based on meter or time to fill container of known volume
- Maintain ~12 inches of water during test, less if close to surficial loose soils
- Record water level, flow rate, and ponding area at end of test
- After test, let water drain out and hand-excavate borehole at least 3-ft deep through bottom of pit to observe soil and groundwater conditions

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USSBP Test in Shallow Well (All New)

- Excavate borehole with vactor truck to a depth of 10 ft
- If soils are suitable (minimal gravel and caving) test may be conducted in a hand-augered borehole or excavated testpit
- Collect soil samples from bottom of borehole at 1-ft intervals using hand auger
- Describe soil and groundwater conditions
- Backfill with bentonite pellets up to bottom of test interval
- Install 2.5 ft of screen and backfill borehole with clean sand or pea gravel
- Top of test interval should be below surficial loose soils and close to maximum water level in proposed infiltration facility (~3 ft of head for shallow infiltration)
- Add water for 6 hours to maintain water level near top of test interval
- If flow rate is greater than 5 gpm, use drop tube that extends below the water level during the test.
- Measure water level with transducer
- Record flow rate during test based on meter or time to fill container of known volume
- Select 1-2 soil sample from test interval or silty layers below test interval for grainsize analysis

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USSBP/CSSBP Test in Deep Well (All New)

- Drill test well using cased drilling approach (sonic, air-rotary) at least 25 ft below target zone or 10 ft into groundwater (which ever is less)
- Collect soil samples from each distinct horizon but at least every 5 ft
- Describe soil and groundwater conditions
- Backfill with bentonite pellets up to bottom of test interval
- When possible, construct well using 2-inch or 4-inch well casing/screen
- Install 5-40 ft of screen and 2-ft longer sandpack across test interval
- Bottom of test interval should be at least 15 ft above groundwater and top of test interval should be at or below bottom of glacial till (or other significant confining layer)
- Add water for 6 hours using drop tube that extends to the top of the screen or below water level during the test, which ever is higher
- Monitor water level with transducer at bottom of casing
- Record flow rate during test based on meter or time to fill container of known volume
- Maintain water level as high as possible during test to determine maximum capacity of test interval
- Select representative soil samples from test interval for grainsize analysis

Analyze Test Results

- Select appropriate soil type based on soil density and grainsize distribution.
- Use this soil type to determine sorption number ($\alpha*$) plus test geometry to select shape fitting factors (Z_1, Z_2, Z_3)
- Calculate K_b using USSBP or CSSBP equation (next slide)
- Calculate % change in flow rate during last hour of test to assess mounding
- Apply appropriate correction factors (uncertainty, well, mounding, clogging) and calculate K_d

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Calculate K_b

Uncased $K_b = \dfrac{C_u Q}{2\pi H^2 + \pi r_e^2 C_u + \frac{2\pi H}{\alpha^*}}$

or when $H/L > 1.2$ use:

Cased $K_b = \dfrac{C_c Q}{2\pi HL + \pi r_e^2 C_c + \frac{2\pi L}{\alpha^*}}$

(Cased same as uncased except some *H*'s replaced by *L*'s and different shape factors)

K_b = bulk hydraulic conductivity

Q = steady state flow

H = steady state head/ponding depth

L = sandpack length

r_e = Equivalent borehole or test pit radius

α^* = sorption number

C_u = Uncased shape factor

C_c = Cased shape factor

Where: $C_{u/c} = \left[\dfrac{(L/r_e)}{Z_1 + Z_2(L/r_e)}\right]^{Z_3}$ (Z_1, Z_2, and Z_3 are fitting parameters

- Easily calculated using spreadsheet
- α^* (sorption number) quantifies capillary suction
- C_u (uncased) and C_c (cased) shape factors quantify geometry of test facility

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Calculate K_d from K_b using Correction Factors

- $K_d = K_b * CF_u * CF_w * CF_m * CF_c$

- Uncertainty Correction Factor (CF_u)
  - Depends on failure risk, number of tests, and test proximity (horizontal and vertical) to full-scale facility
  - 0.2-0.5 for high-risk facilities with limited testing
  - 1 for low-risk facilities with ideal testing

- Well Correction Factor (CF_w)
  - Use 0.5 when well test used to size horizontal facility (pond or bioretention)
  - Use 1.0 when well test used to size drywell

- Mounding Correction Factor (CF_m)
  - Needs more detailed analysis
  - Not necessary if groundwater mounding analysis is conducted
  - Groundwater mounding can occur on perching layers even if there is no saturated soils
  - Depends on size of full-scale facility and proximity to steady-state during last hour of test
  - Use 0.5 for large facility when flow rate still decreasing significantly during last hour of test
  - Use 1 for small facility and steady flow rate achieved during last hour of test

- Clogging Correction Factor (CF_c)
  - Not addressed in this study
  - Use 0.5 for high traffic site
  - Use 1.0 for low traffic sites

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Using K_d to Calculate Well Capacity (Q) and Infiltration Rate (I)

$$Q = \left(\frac{K_d}{C_u}\right)\left(2\pi H^2 + \pi r_b^2 C_u + \frac{2\pi H}{\alpha^*}\right)$$

or when $H/L > 1.2$ use:

$$Q = \left(\frac{K_d}{C_c}\right)\left(2\pi HL + \pi r_b^2 C_c + \frac{2\pi L}{\alpha^*}\right)$$

$$I = \frac{Q}{Facility\ Area}$$

I = infiltration rate

K_d = design hydraulic conductivity

Q = steady state flow

H = steady state head/ponding depth

L = sandpack length

r_b = borehole or effective facility radius: $r_b = \sqrt{\frac{Facility\ Area}{\pi}}$

α^* = sorption number

C_u = Uncased shape factor

C_c = Cased shape factor

- Q as a function of stage (H) easily calculated using spreadsheet
- Drywells can be simulated in WWHM using SSD Table
- For shallow infiltration facilities, infiltration rate can be calculated using an average ponding depth

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More Information

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