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AWRA VIRTUAL ANNUAL WATER RESOURCES CONFERENCE

NOVEMBER 9 – 11, 2020

AWRA 2020 VIRTUAL ANNUAL WATER RESOURCES CONFERENCE

A Unified Method for Infiltration Testing and Predicting Infiltration Performance

Session #2A Session 1

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Topics Covered

- Summary of infiltration testing methods in Washington State and Los Angeles County
- Limitations of current methodologies
- Introducing the steady-state borehole permeameter (BP) method, which is suitable for both horizontal infiltration and vertical infiltration (thus, the “unified” method)
- Demonstrating how the BP method can be used to predicting the performance of infiltration facilities

What Will You Learn

- Current methods give different infiltration/percolation rates for different sized infiltration test facilities
- Steady head infiltration rates do not equal falling head infiltration rates
- In theory, the borehole permeameter (BP) method provides the same saturated hydraulic conductivity (K_s) value no matter the size or shape of the infiltration facility
- Calibrated BP fitting parameters are different for glacially-consolidated soils (Kindred and Reynolds, 2020) than normally-consolidated soils

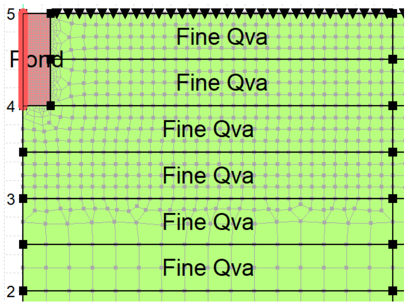
Modeling Assumptions for Wash. State Infiltration Methods and Hypothetical Bioretention Facility

Test	Ponding Area	Ponding Depth	Type	Test Duration
Simple Test (Seattle)	3.1 sf	12 in.	Falling head	4.5 hr
Small PIT	20 sf	12 in.	Fixed head	8 hr
Large PIT	100 sf	12 in.	Fixed head	8 hr
Bioretention Facility	1,000 sf	6 in.	Fixed head	8 hr

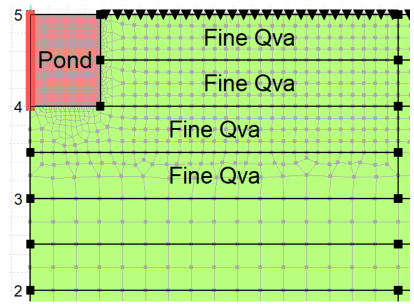
PIT = Pilot Infiltration Test

Numerical Simulations use Axisymmetric Domains

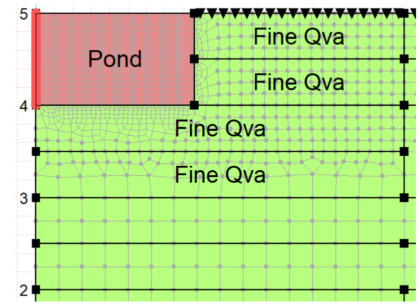
Simple Test



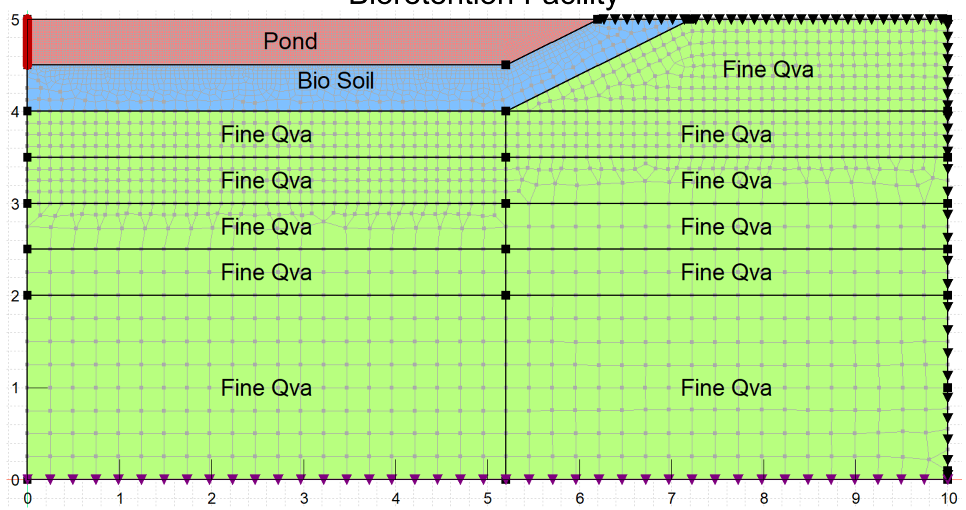
Small PIT



Large PIT



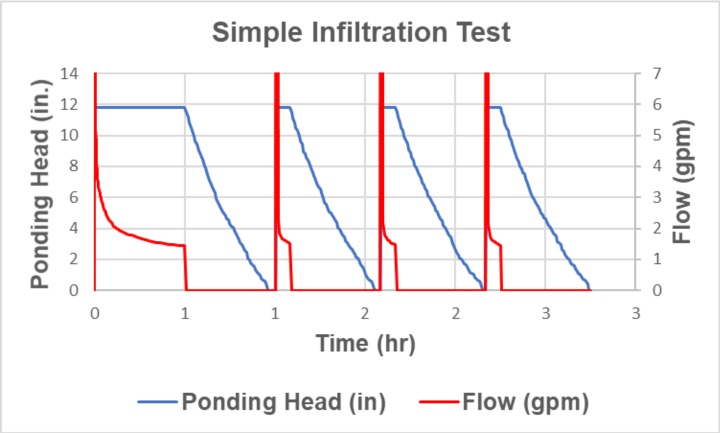
Bioretention Facility

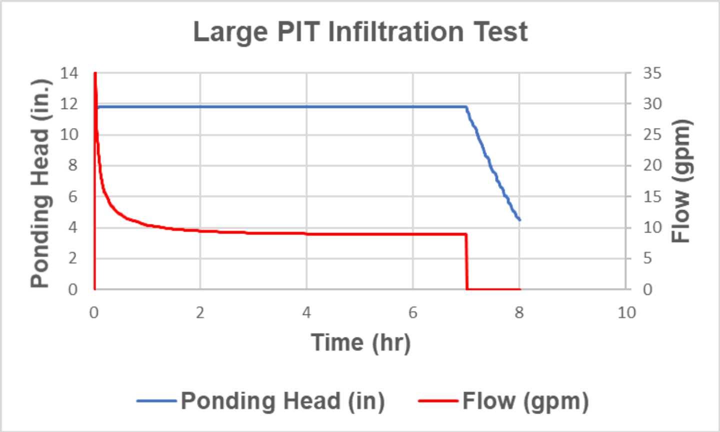


Fine Qva:
K = 3.3 inch/hr

(Dimensions in meters.)

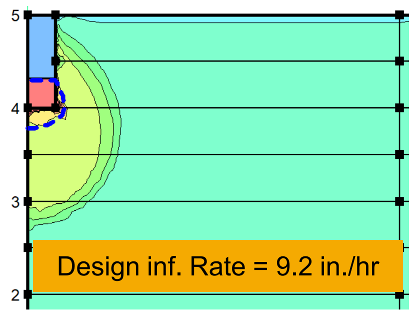
Infiltration Test Ponding Results



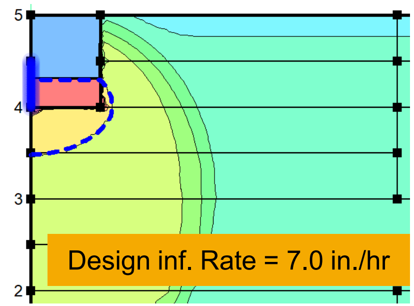


Wash. State Infiltration Test Results

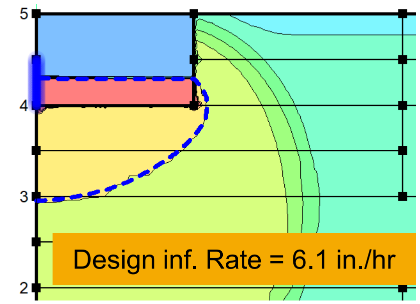
Simple Test (4th fill)



Small PIT (7 hr)

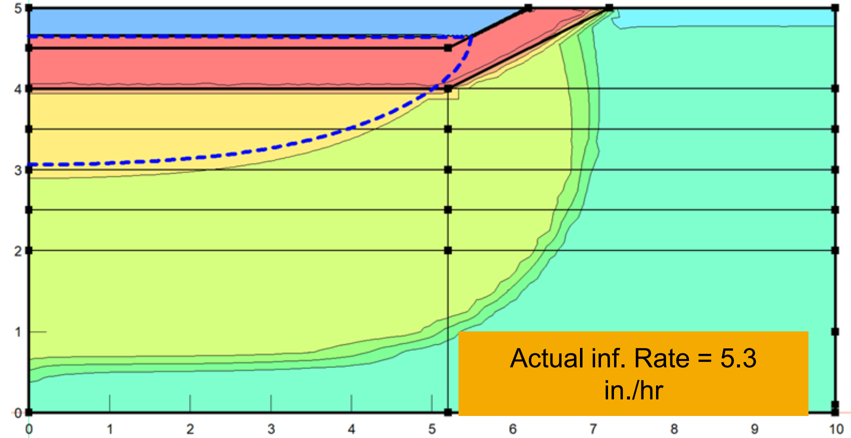


Large PIT (7 hr)

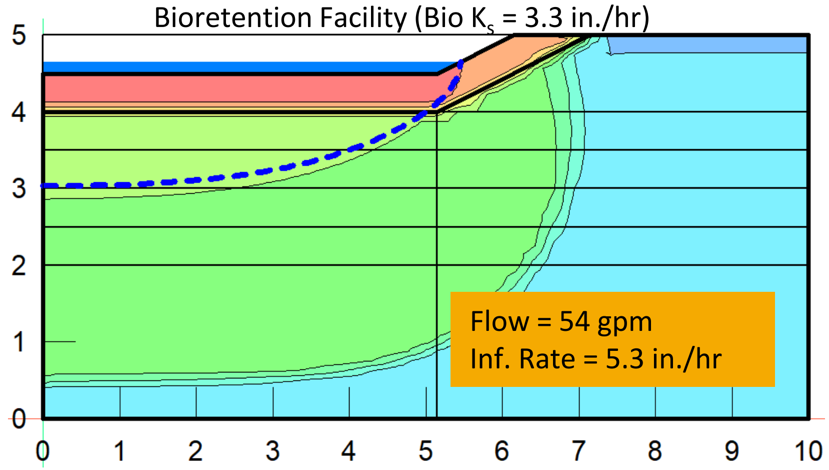


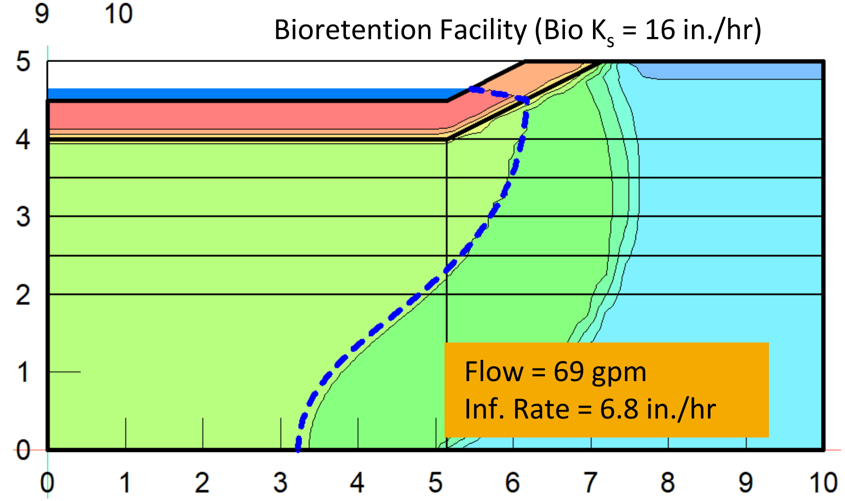
Bioretention Facility (7 hr)

Bioretention Soil K = 3.3 in./hr



Bioretention Soil K Affects Performance





Wash. State Infiltration Test Results

Test	Flow (gpm)	Fixed Head Infiltration	Falling Head Infiltration	Correction Factor[2]	Design Rate
Simple (Seattle)		<46 in./hr[1]	18.4 in./hr	0.5	9.2 in./hr
Small PIT	2.6	15.6 in./hr	10.2 in./hr	0.45	7.0 in./hr
Large PIT	7.5	8.9 in./hr	6.6 in./hr	0.68	6.1 in./hr
Bio. Facility (Bio K_s = 3.3 in./hr)	46	5.3 in./hr	4.3 in./hr		
Bio. Facility (Bio K_s = 16 in./hr)	59	6.8 in./hr	5.8 in./hr		

Key Takeaways:

1) Falling head infiltration rates are always less than fixed head infiltration rates.
2) Measured infiltration rates are much higher than K_s of the native soil (3.3 in./hr).
3) All three methods provide different design rates.

Notes:

[1] Not at steady state after 30 minutes.

[2] The measured rates are multiplied by the correction factor to obtain the design rate. These correction factors only includes the correction for test method and clogging. The variability correction factor assumed to be 1.0 (recommended range is 0.33-1.0).

Los Angeles County Infiltration Test Methods

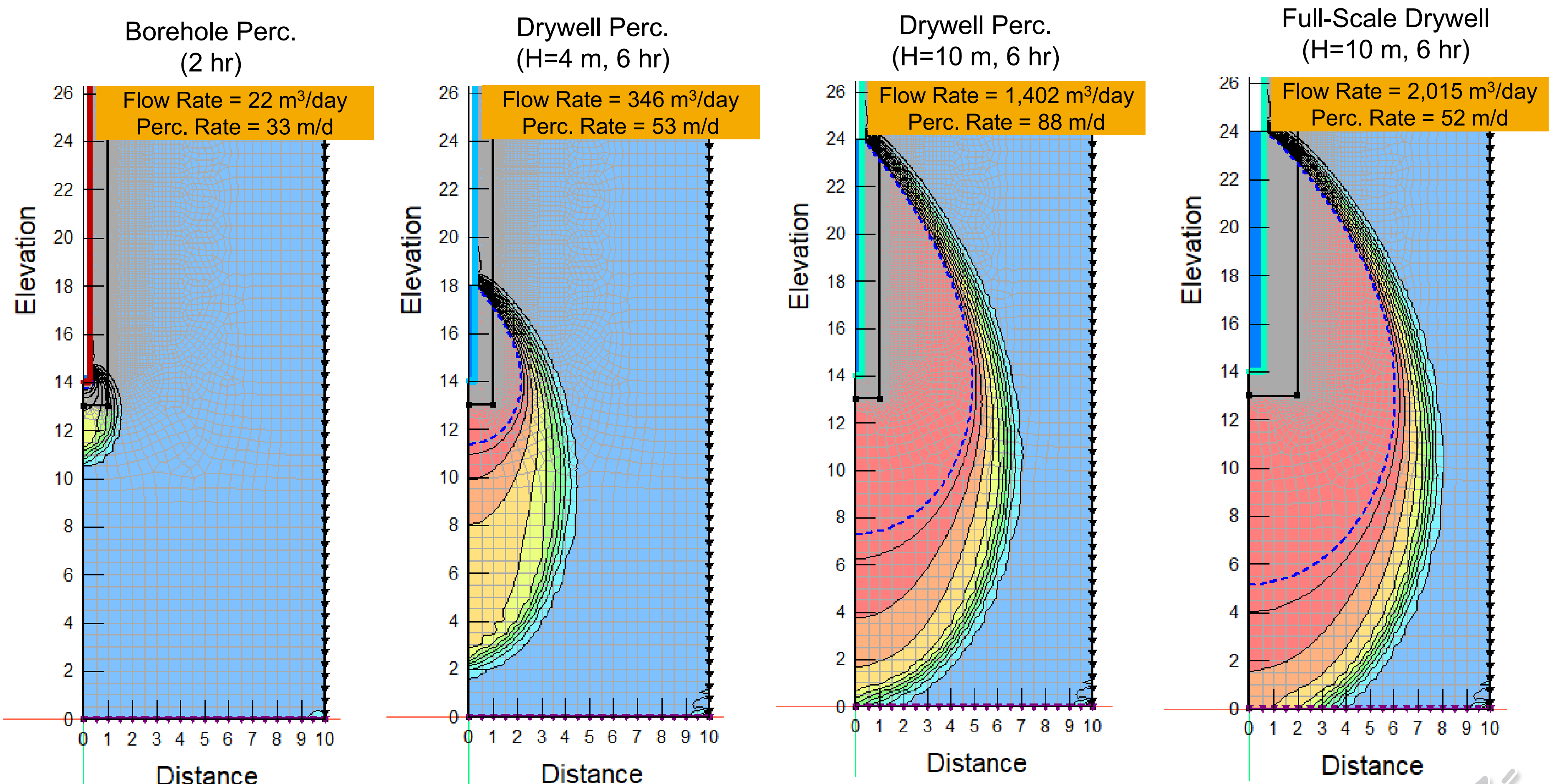
- All methods provide a “percolation rate” which is flow divided by total saturated area of facility, including bottom and sides
- Shallow infiltration methods:
  - Double-ring infiltrometer test (ASTM D3385)
  - Excavation Percolation Test (small-scale falling-head test similar to Seattle Simple Test)
  - High Flowrate Percolation Test (small-scale 2-hr steady state test)
  - Infiltration Basin Percolation Test (very similar to Washington State PIT)
- Methods suitable for drywells:
  - Well Permeameter Test (USBR 7300-89)
  - Boring Percolation Test Procedure
  - Drywell Percolation Test

Modeling Assumptions for Borehole/Drywell Percolation Tests and Full-Scale Drywell

Test	Well Diameter	Ponding Depth (H)	Test Duration
High Flowrate Borehole Percolation Test	50 cm	0.3 m	2 hr
Drywell Percolation Test (H = 4 m)	50 cm	4 m	6 hr
Drywell Percolation Test (H = 10 m)	50 cm	10 m	6 hr
Full-Scale Drywell (H = 10 m)	120 cm	10 m	6 hr

All methods are steady-state flow methods.
Only differences between the three test are ponding depth and test duration.

Borehole Infiltration Test Results (Fine-medium Qva, K = 10 m/day)



Summary of LA County Infiltration Testing Methods

- Shallow infiltration testing methods in LA county as similar Washington State methods (with the same issues)
- Drywell test methods can either under-predict or over-predict drywell performance depending on test geometry
- Drywell tests should be conducted across the same saturated interval as the proposed full-scale drywell

Borehole Permeameter (BP) Steady State Equation

(Kindred and Reynolds, 2020)

$$K_S = \frac{CQ}{2\pi H^2 + \pi r^2 C + \frac{2\pi H}{\alpha^*}} \quad (Equation\ 1)$$

Hydrostatic Pressure Flow

Vertical Gravity Flow

Capillarity Flow

Where:

- K_s = Field saturated hydraulic conductivity (feet/day)
- Q = Steady state flow (cubic feet/day)
- H = Steady state head/ponding Depth (feet)
- r = Radius of test facility (feet)
- α^* = Porous media sorption number (1/feet)
- C = Shape factor (dimensionless)

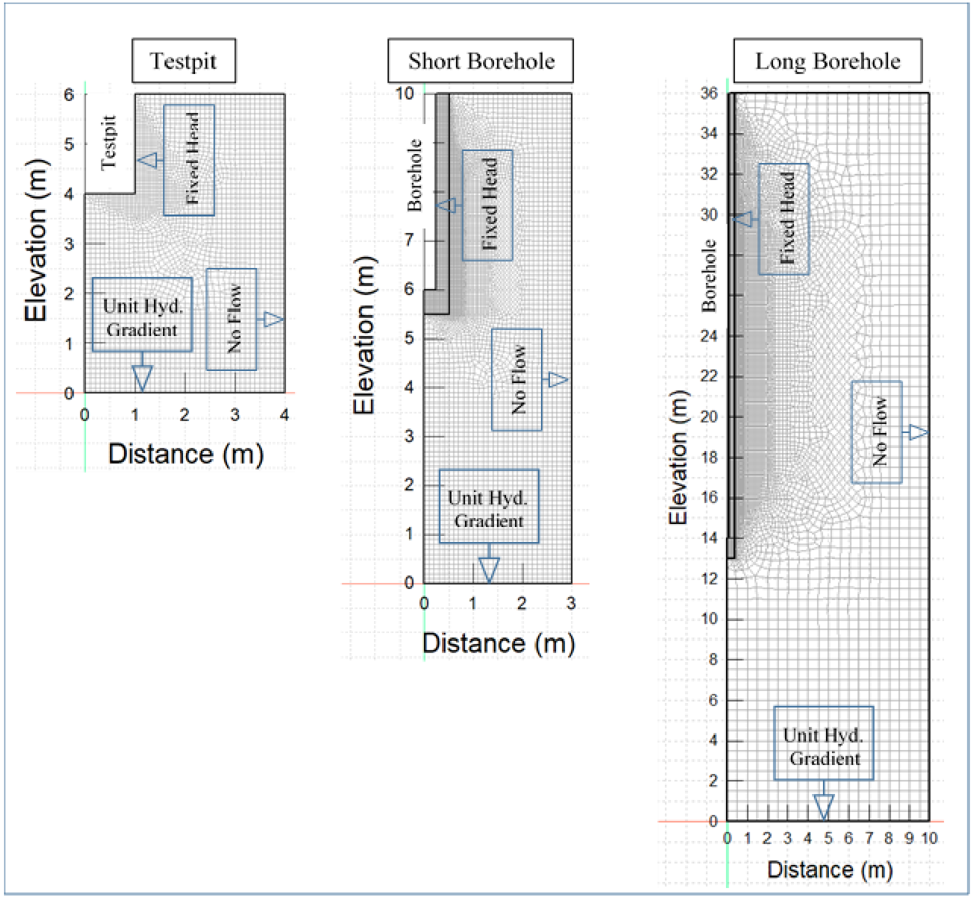
Where: $$C = \left[\frac{(H/r)}{Z_1 + Z_2 (H/r)}\right]^{Z_3} \quad \text{(Zhang et al., 1998)}$$

Kindred, J.S. and W.D. Reynolds, 2020, Using the borehole permeameter to estimate saturated hydraulic conductivity for glacially over-consolidated soils, Hydrogeology Journal. Download at https://kindredhydro.com/kindred-and-reynolds-2020

Glacial Soils - Calibration Approach

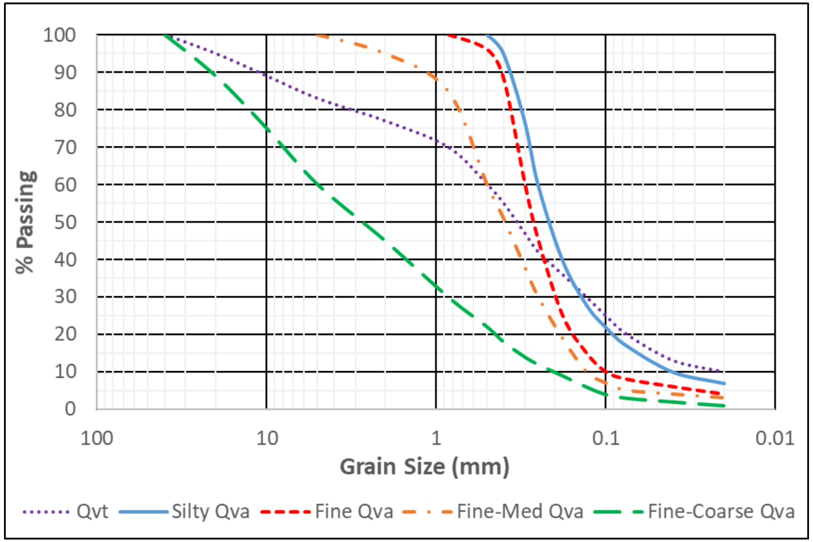
- Conduct numerical simulations using SEEP/W
- Fitting parameters for normally consolidated soils over-predicted Ks by up to 94%
- Conduct axisymmetric numerical simulations intended to represent the range of infiltration tests:
  - 15 test geometries
  - 5 glacial soils (4 advance outwash and 1 glacial till soil)
  - 2 K_s values for each soil type
  - For a total of 150 simulations
- Develop BP fitting parameters (Z_1, Z_2, and Z_3) that minimize maximum error across all the simulations

Numerical Simulation – 15 Geometries



Test Hole Type	r (m)	H (m)	H/r Ratio
Test pit	1.0	0.05	0.05
Test pit	1.0	0.1	0.1
Test pit	1.0	0.25	0.25
Test pit	1.0	0.5	0.5
Test pit	1.0	1.0	1
Short Borehole	0.25	0.25	1
Short Borehole	0.25	0.5	2
Short Borehole	0.25	1.0	4
Short Borehole	0.25	2.0	8
Short Borehole	0.25	3	12
Long Borehole	0.1	1.2	12
Long Borehole	0.1	2	20
Long Borehole	0.1	4	40
Long Borehole	0.1	10	100
Long Borehole	0.1	20	200

Numerical Simulation – 5 Soil Types with 2 K Values

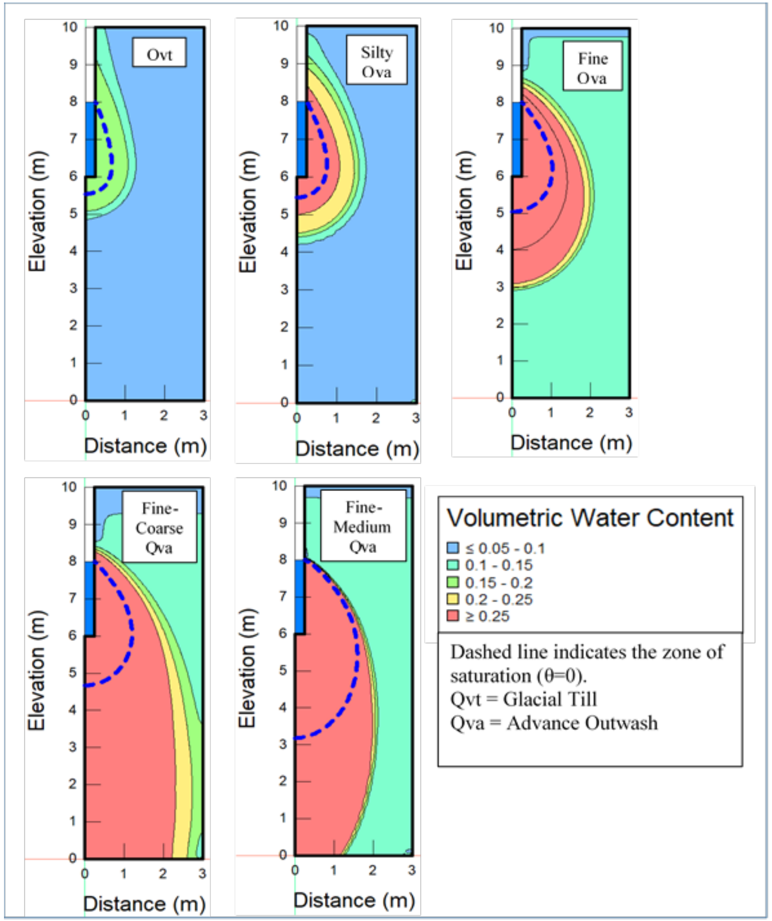


Qvt = Glacial till

Qva = Advance outwash

Parameter	Soil Type				
	Qvt	**Silty Qva**	**Fine Qva**	**Fine-Medium Qva**	**Fine-Coarse Qva**
D_{60} (mm)	0.5	0.25	0.3	0.5	5
D_{10} (mm)	0.02	0.04	0.1	0.13	0.25
Silt Content	20%	17%	8%	5%	3%
USCS Soil Type	SM	SM	SM-SP	SP	SW
Porosity (θ_{sat})	17%	25%	30%	30%	30%
Saturated Hydraulic Conductivity K_s (inch/hr)	0.16/0.32	0.8/1.6	3.3/6.6	16/32	8/16
Sorption Factor α^* (ft^{-1})	0.36	0.41	0.76	1.2	7.6

Example Results for Short Borehole with H = 2 m



Summary of Calibration Results

- Calibrated BP "Z" parameters based on comparison with 150 numerical simulations
- Used Excel Goal Seek to minimize maximum error
- Calculated unique α* for each soil type
- Developed 4 sets of Z parameters based on H/r ratio and USCS class

Soil Type	α* (ft⁻¹)	Low Head (H/r<20)			High Head (H/r>20)		
		Z_1	Z_2	Z_3	Z_1	Z_2	Z_3
Qvt (SM)	0.36	2.65	0.177	0.904	2.84	0.0294	0.605
Silty Qva (SM)	0.41						
Fine Qva (SP-SM)	0.76	2.23	0.184	0.968	2.41	0.0296	0.626
Fine-Medium Qva (SP)	1.2						
Fine-Coarse Qva (SW)	7.6						

- Maximum error of 2%-13% depending on soil type and H/r ratio.
- Generally more error for fine-grained soils and less error for coarse-grained soils

Using the BP Method to Predict Performance

The BP equation can be re-arranged to predict maximum Q of an infiltration facility given K_s, α^*, and C:

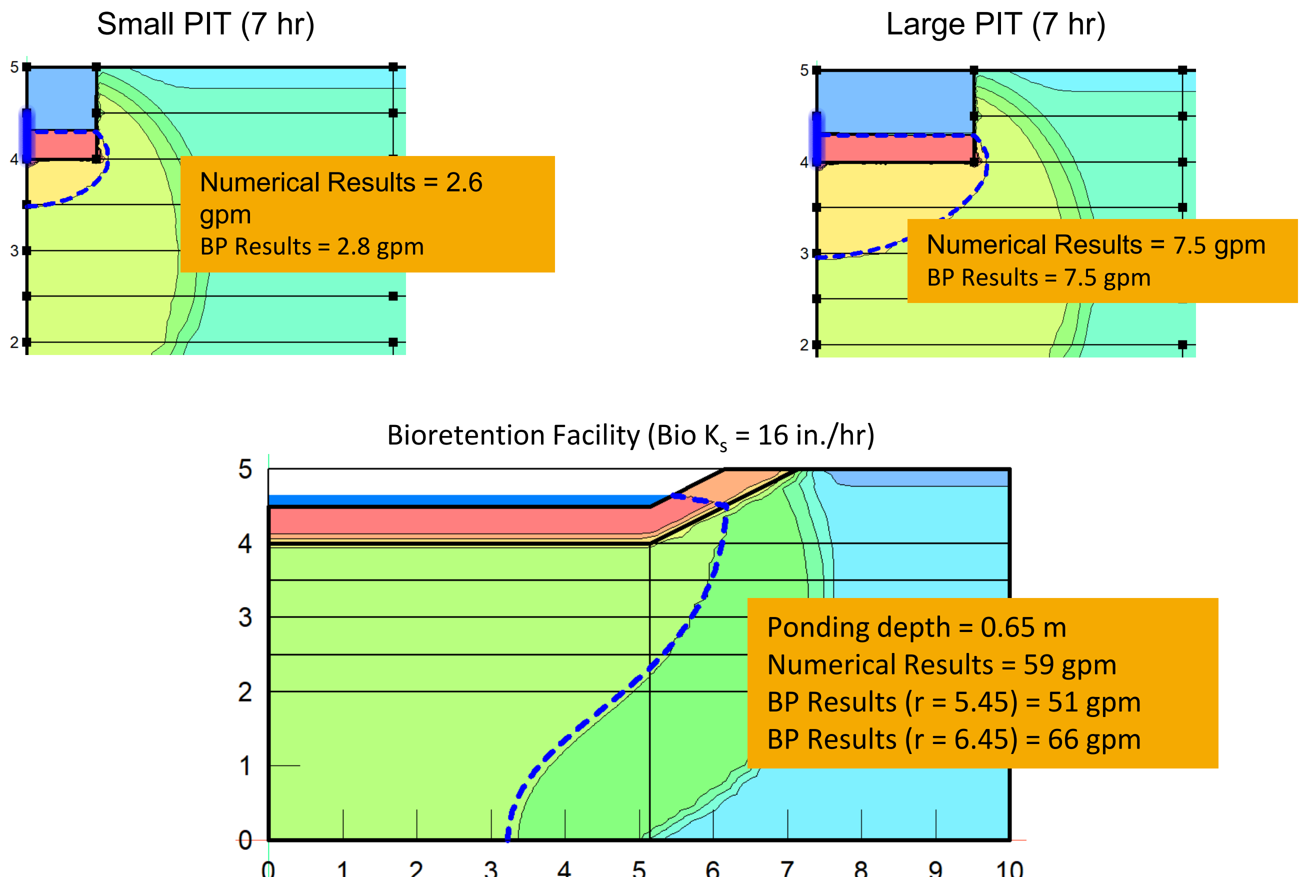
$$Q = K_s \left[\frac{2\pi H^2}{C} + \pi r_e^2 + \frac{2\pi H}{C\alpha^*}\right]$$

Results (Q) for a 4-ft deep drywell in fine Qva:

	Radius (r) = 5.0 **Area = 78.5 sf**	**Radius (r) = 7.1 ft** **Area = 157 sf**
Head (H) = 0.1 ft	Q = 4.1 gpm	Q = 9.5 gpm
Head (H) = 4.0 ft	Q = 12.5 gpm	Q = 23.5 gpm

Note that flow increases by a factor of 2.5 to 3.0 as ponding head increases from 0.1 to 4.0 feet.

BP Estimates of Performance



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