THE ORANGE COUNTY WATER DISTRICT RIVERBED FILTRATION PILOT PROJECT: MODELING OF LATERAL DRAIN PERFORMANCE TO GUIDE PROJECT DESIGN

GSA GeoSystems Analysis, Inc. Innovations in Hydrology

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ABSTRACT

Two-dimensional variably saturated flow modeling coupled with pipe fluid flow calculations were used to guide the design of a riverbed filtration pilot project system. Modeling considered a system of shallow subsurface lateral drains and varied the drain lengths, diameters, spacing intervals, and drain placement depths below ground surface to evaluate the potential of the system to increase riverbed recharge with subsurface capture of 300 liters per second. Predicted lateral drain system collection performance at drain spacings of 25 m and 50 m apart were similar, but the performance decreased significantly at 12.5 m spacing in response to reduced hydraulic head and the development of laterally continuous unsaturated conditions. Predicted drain collection system performance increased with deeper lateral depths as a result of greater hydraulic head above the drain system, however, increased performance did not offset the resultant increase in installation costs. Lateral diameter was predicted to have minimal effect on collection rates, but significantly influenced the drain system performance due to changes in pipe flow capacity. The implemented pilot study lateral drain system achieved a maximum pumping rate of 40% of modeling predictions. The discrepancy between predicted and maximum collection capacity is believed to be due to actual groundwater elevations being lower than assumed in the model, and large variability in surface water depth over the system. Nonetheless, the model served as a valuable design tool and can be optimized with pilot study observations to support project scale up.

BACKGROUND and METHODS

- Orange County Water District (OCWD) recharges over 280 million m^3/year of Santa Ana River (SAR) water.
- OCWD wants to increase recharge volumes by improving recharge water quality and inducing recharge through riverbed filtration.
- Objective: Design a pilot-scale riverbed filtration system to capture and treat 17 m^3/minute of SAR water.
- Riverbed filtration system design guided by two-dimensional model (HYDRUS-2D; Simunek et al., 1999) of shallow subsurface with lateral drains.
  - Model domain considered variable depth and spacing of lateral drains (Figure 1).
  - Lateral drain spacing of 12.5, 25, or 50 m; drain depth of 1.5 or 3 m; drain diameter of 15 or 30 cm.
  - A foulant layer (Layer 1) was incorporated to evaluate the formation of surface clogging that could reduce recharge.
  - Model boundary conditions:
    - Bottom = seepage face to represent capillary break between silty clay layer and underlying sandy aquifer material;
    - Side = No flow;
    - Top = Constant head representing a surface water level of 0.3 m;
    - Lateral Drain = Circular seepage face.
- Pipe flow capacities for 15, 20, and 30 cm diameter lateral drains calculated using Manning's equation assuming:
  - Linear velocity within the drain does not exceed 120 m/min to avoid head loss due to pipe wall resistance, and;
  - Optimum linear velocity is 90 m/min.
- Results from each scenario compared by calculating lateral drain length required to collect 17 m^3/min.

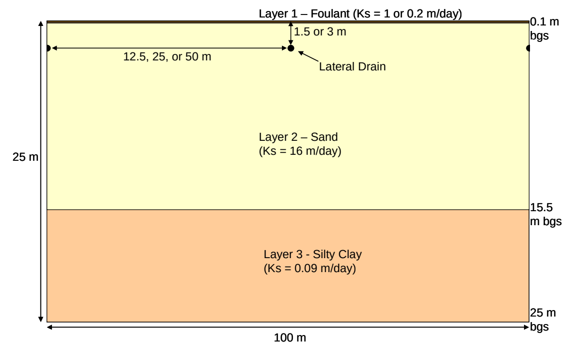

Figure 1. Model domain (Ks = Saturated Hydraulic Conductivity; bgs = below ground surface).

RESULTS

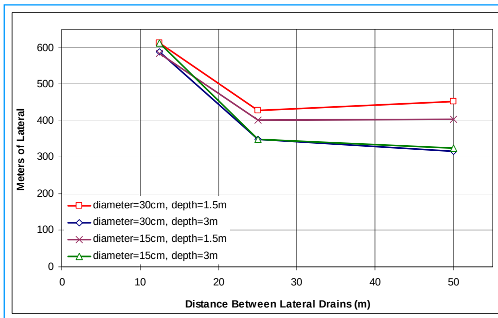

Figure 2. Simulated total length of lateral drain pipe needed to capture 17 m^3/min.

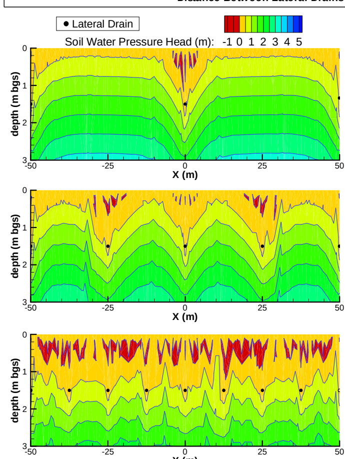

Figure 3. Simulated steady-state soil-water pressures for 15 cm diameter, 1.5 m bgs lateral drains at 50 m (top), 25 m (middle), and 12.5 m (bottom) spacing.

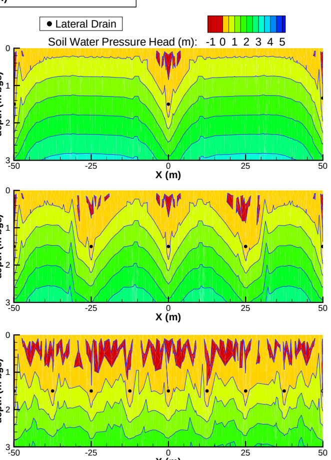

Figure 4. Simulated steady-state soil-water pressures for 30 cm diameter, 1.5 m bgs lateral drains at 50 m (top), 25 m (middle), and 12.5 m (bottom) spacing.

Table 1. Calculated maximum individual drain length and associated flow rate at which either inflow volume surpasses drain capacity or flow velocity exceeds 120 m/min.

Lateral Drain Diameter (cm)	Drain Depth (m bgs)	Lateral Drain Spacing (m)	Maximum Lateral Drain Length (m)	Flow at Maximum Lateral Drain Length (m^3/min)
30	1.5	50	151	6.3
30	1.5	25	146	6.5
30	1.5	12.5	185	5.7
30	3	50	147	8.9
30	3	25	158	8.6
30	3	12.5	224	7.2
20	1.5	50	73	9.1
20	1.5	25	71	9.2
20	1.5	12.5	90	8.2
20	3	50	72	12.7
20	3	25	77	12.3
20	3	12.5	109	10.3
15	1.5	50	41	1.9
15	1.5	25	41	1.9
15	1.5	12.5	53	1.7
15	3	50	44	2.6
15	3	25	46	2.5
15	3	12.5	67	2.1

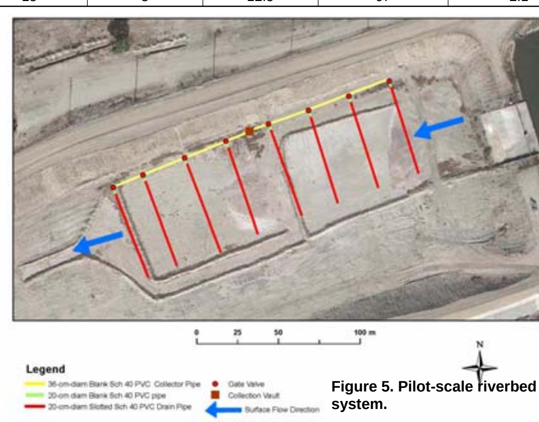

Figure 5. Pilot-scale riverbed filtration system.

CONCLUSIONS

- Deeper lateral drain placement depth predicted to increase system capacity (less drain length required, Figure 2).
- Decrease in efficiency going from 15 cm and 30 cm diameter drain size at 1.5 m bgs depth (Figure 2) due to increased desaturation in vicinity of drain (lower head on drain system).
- Desaturation primarily limited to a depth of 1 m bgs; as lateral drain spacing becomes smaller the desaturated layer increases across the width of the domain (Figures 3 and 4).
- 15 cm diameter lateral drains carry substantially less flow and produce greater restrictions on lateral drain system configuration (Table 1).
- Lateral drain lengths needed to achieve 17 m^3/min spacing are similar at 50 and 25 m (Figure 2), however, 25 m spacing allows for a smaller footprint.
- A 3 m bgs lateral drain depth is more efficient than 1.5 m bgs, however, the gain in efficiency is reduced due to added cost for deeper excavation and lateral drain installation (Figure 1, Table 1).
- Decreasing the surface foulant layer saturated hydraulic conductivity to 0.2 m/day resulted in reduced infiltration and desaturation across the domain to the depth of the lateral drains, and a five-fold decrease in system capacity, regardless of lateral diameter or depth (data not shown).
- Pilot system built using 20 cm diameter lateral drains at 25 m spacing and 1.5 m bgs (Figure 5).
- Observed pilot study maximum capacity was approximately 40% of design, due to absence of the silty clay layer (Layer 3) and lower than anticipated groundwater elevations in the vicinity of the pilot project (Milczarek et al., 2010).
- Calibration of the variably saturated flow model can be used to assist in project scale-up.

Milczarek, M., J. Keller, G. Woodside, A. Hutchinson, R. Rice, and A. Canfield, 2010. The Orange County Water District riverbed filtration pilot project: water quality and recharge improvements using induced riverbed filtration. Presented at ISMAR 7, Abu Dhabi, October 9 – 13, 2010.

Simunek, J., M. Sejna, and M. Th. Van Genuchten, 1999. The HYDRUS-2D software package for simulation of two-dimensional movement of water, heat, and multiple solutes in variably saturated media. Version 2.102, International Ground Water Modeling Center, Colorado School of Mines, Golden, CO.