

Enhancement of remediation pilot test data using groundwater modelling: a case study

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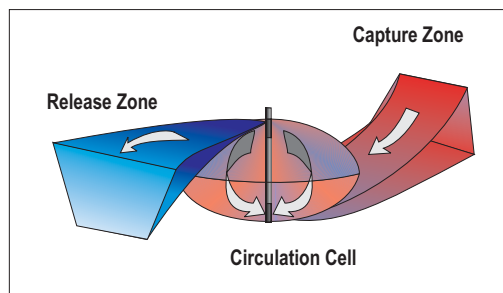
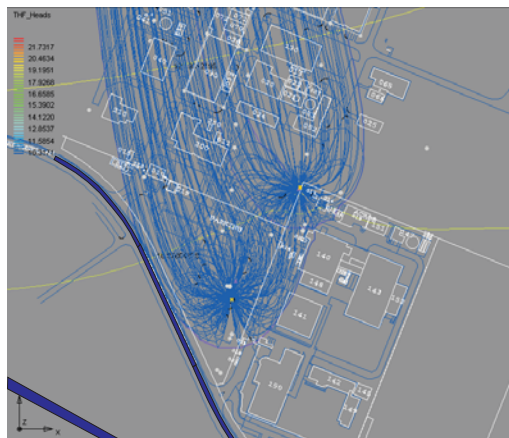
Abstract In groundwater remediation, Groundwater Circulation Wells (GCW) are used as an alternative to typical Pump & Treat (P&T) methods. Extraction and injection are operated in a single well with multiple isolated screened intervals, which creates a three-dimensional flow pattern (circulation cell) in the aquifer.

The utility of GCW pump test data can be increased using groundwater modelling to assess remediation feasibility. Simulating pilot tests gives a unique opportunity to calibrate key flow parameters such as vertical hydraulic conductivity (Kv) and better definition of hydrogeologic units. GCW pump tests were simulated using both steady-state and transient MODFLOW models. This paper describes modelling hypotheses, grid design, boundary conditions and material properties. The calibration procedure is then discussed in detail including sensitivity studies and automatic calibration. Finally, advantages and drawbacks are listed as well as likely improvements including the use of a finite-element code to more accurately simulate radial flow. Using both trial-and-error and automated techniques enabled focused and efficient model calibration.

This study was a pioneering work and contributed in installing the first GCWs in Belgium. It provided a stronger basis to demonstrate the effectiveness of GCW technologies and played a key role in the acceptance of the remedial plan by local regulators.

INTRODUCTION

Numerical modeling is not only intended to simulate hydrodynamic and hydrodispersive phenomena that occur in groundwater. The effects of active groundwater remediation can be evaluated using groundwater models. These can be fundamental for systems which must have design lives that extend potentially into several decades.

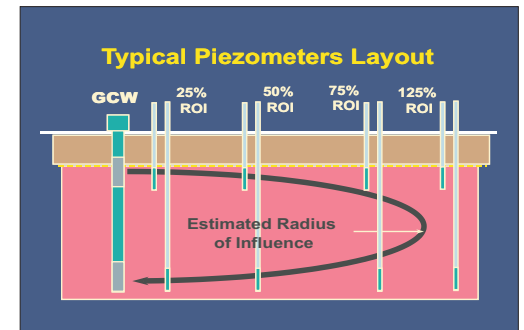
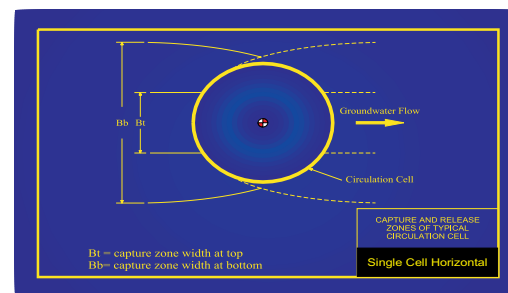


GROUNDWATER CIRCULATION WELL

Groundwater Circulation Wells (GCW) are an Advanced Remediation Technology (ART) and are used as an alternative to typical Pump & Treat (P&T) methods (Herrling & Stamm, 1992; Lakhwala *et al.*, 1998; Elmore & DeAngelis, 2004). The typical GCW consists of installing and operating a single well with two isolated screened intervals. Groundwater is extracted from one screen and after treatment it is injected back into the aquifer through the second screen, which creates a three-dimensional flow pattern (circulation cell) in the aquifer. Both downward and upward circulation modes can be created according to the site-specific boundary conditions.

DIPOLE FLOW TEST

Since the early 1990's, GCWs have been studied in the context of aquifer characterization and theories have been developed accordingly known as Dipole Flow Tests (DFT) (Kabala, 1993; Zlotnik & Ledder, 1996). Circulating groundwater between two screens develops a dipole-like flow regime instead of a predominantly horizontal one (Kabala, 1993). In this case, induced head changes are strongly dependent on both horizontal and vertical hydraulic conductivities (Kh and Kv). Therefore, simulating a GCW pump test gives a unique opportunity to study the hydraulic conductivity distribution on a scale compatible with the typical grid frame of groundwater models required to develop remediation scenarios.



GCW PILOT TEST

GCW pilot tests have recently been conducted by URS at two industrial sites within the Diestian sands in Northern Belgium (Cosme *et al.*, 2003). The investigated aquifers consist of 100 to 160 meters of sandy marine deposits, and fully saturated till approximately 2 to 3 meter below ground level (mbgl).

A total of 6 circulation cells have been pilot tested using flow rates ranging between 5 and 30 m³.h⁻¹. These dipole systems were installed at depths varying between 45 and 100 mbgl and, with separation distances between the upper and lower screens of 25 to 50 meters.

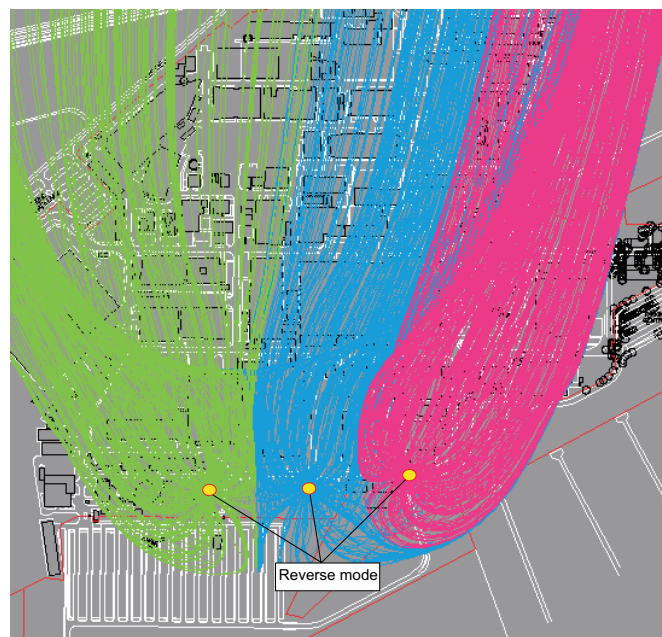
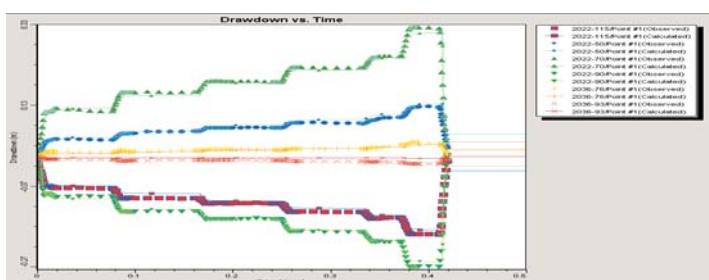
PUMP TEST MODELLING AND PARAMETER CALIBRATION

Groundwater flow models of the investigated sites were first prepared using MODFLOW and calibrated to steady-state conditions using conventional trial-and-error techniques wherein static piezometric heads were compared to calculated values.

The layering and grids of these models were then refined to simulate more accurately the GCW pump tests. The preliminary hydraulic properties from the calibrated steady-state models were used as initial model-input values. Steady-state pumping simulations were primarily calibrated by comparing induced head changes obtained at equilibrium with calculated values. According to the induced aquifer response, decrease or increase in piezometric heads in surrounding monitoring wells, hydrogeologic units were defined more accurately.

Pump test simulations were then run using transient flow models. A similar approach was used to further refine the hydraulic conductivity values. The most significant adjustments were made to the vertical hydraulic conductivity, K_v, which varied up to one order of magnitude as compared to the values obtained from the initial steady-state flow modelling. Transient modelling also allowed a focus on storage. Deep phreatic sandy aquifers show typical confined aquifer response, and the storativity was consequently reduced in the lower part of the models.

Finally, the deduced hydraulic properties were imported in the original static flow models. Automatic calibration was applied using PEST (Doherty *et al.*, 1994) as a final cross-calibration test. Obtained objective functions became slightly lower than the primary ones but it did not significantly change the hydraulic properties issued from the transient pump test simulations. These results contributed in confirming the effectiveness of the overall calibration approach.



CONCLUSION

This paper has attempted to illustrate the helpfulness of enhancing remediation pilot test data using groundwater modelling. In addition to the feasibility aspects and the acceptance of an appropriate remediation strategy by regulators, groundwater modelling brought new fundamental elements including a better definition of hydrogeologic units and more reliable vertical hydraulic conductivities. This work also provided insight regarding how to perform future pilot tests, and regarding what data needs to be collected to provide reliable results.

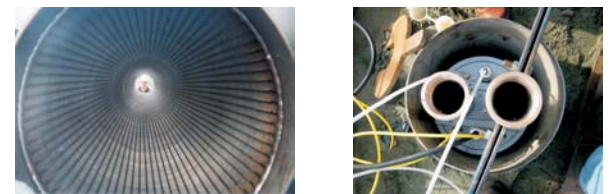
REFERENCES

- Cosme F., Vermeiren G., Lakhwala F., Overmeire A., De Buyscher G. & Op de Beeck N. (2003) Pilot Test to Assess the Effectiveness of Groundwater Circulation Well Technology. 8th International FZK/TNO Conference on Contaminated Soil, Ghent, Belgium. Proceeding Paper.
- Doherty J., Brebber L. & Whyte P. (1994) PEST Model-Dependent Parameter Estimation. User's manual. Watermark computing, Australia.
- Elmore A.C. & DeAngelis L. (2004) Modeling a Ground Water Circulation Well Alternative. Ground Water Monitoring & Remediation, 24(1), 66-73.
- Herrling B. & Stamm J. (1992) Numerical Results of Calculated 3D Vertical Circulation Flows around Wells with Two Screen Sections for in-situ on-site Aquifer Remediation. In: Computational Methods in Water Resources IX, vol. I, Numerical Methods in Water Resources (edited by T. F. Russel, R. E. Swing, C. A. Brebbia, W. G. Gray & G. F. Pinder), 483-492, Elsevier Sci., New York.
- Kabala Z. J. (1993) The Dipole Flow Test: A New Single-Borehole Test for Aquifer Characterization. Water Resources Research, 29(1), 99-107.
- Lakhwala F., Mueller J.G. & Desrosiers R.J. (1998) Demonstration of a Microbiologically Enhanced Vertical Ground Water Circulation Well Technology at a Superfund Site. Ground Water Monitoring & Remediation, 18(3), 97-106.
- Zlotnik V. & Ledder G. (1996) Theory of Dipole Flow in Uniform Anisotropic Aquifers. Water Resources Research, 32(4), 1119-1128.

DISCUSSION

More reliable results were found by focusing on head changes from surrounding monitoring wells rather than those recorded in the GCW. Well diameters used for GCWs are large, usually ranging between 200 and 400 mm. In addition, the pumping and injection chambers are not restricted to the screened intervals. Several meters of blind casing above or under the screen can increase the well bore storage. This can result in larger than ideally expected head changes in the GCW itself.

Plots showing the evolution of head changes as a function of recirculation flow rates were carried out. These plots showed a distinct difference in how GCW's respond as compared to the responses in the aquifer. In monitoring wells, the relationship between the head changes and the circulation flow rate was nearly linear while in the GCW, the head changes tended to increase dramatically at high flow rates. This trend was more significant in the injection screen than in the extraction screen.



Attempts to mimic this behaviour in the model by varying permeability and storage properties adjacent to the GCW to account for local heterogeneity were not entirely successful. Therefore, it is likely that well construction or hysteresis also influence observed aquifer responses.

Finite-difference models, such as used to model GCW tests discussed in this paper have certain limitations due to the imposed rectangular grid. Modelling could be improved using a finite-element code such as FEFLOW, which can simulate radial flow patterns (at least horizontally) more accurately while using a smaller mesh than required by traditional finite-difference models. Future work on these tests will investigate and evaluate the advantages of applying finite-element models to the analysis of GCW tests.