PFOS MOBILITY AND REMEDIATION IN THE GROUNDWATER ZONE OF GLACIOFLUVIAL SEDIMENTS, GARDERMOEN, NORWAY

Kevin J. Tuttle[1)], Bente Wejden[2)], Anne Fevang[1)] and Jostein Skjefstad[2)]

[1)] Norconsult AS, Vestfjordgate 4, N-1338 Sandvika, Norway
[2)] Oslo Lufthavn AS, Edvard Munchs veg, N-2061 Gardermoen, Norway
Kevin.Tuttle@norconsult.com

Introduction

On the 10^{th} of September 2010, approximately 40kg of PFOS in fire suppressants was accidently released into an infiltration-magazine for surface-water runoff at the Oslo International Airport, Gardermoen. The infiltration-magazine is situated in glaciofluvial sediments above Norways's largest phreatic groundwater aquifers. Research on PFOS has shown varying but very low sorption potentials (Ferry and Wilson, 2009; Gellrich and Knepper, 2012). Glaciofluvial sediments are known to contain limited amounts of organic particles to which contaminants can adhere to. Under the geological conditions at Gardermoen where PFOS is registered in low-organic coarse-grained permeable sediments, the contaminant is monitored having high advection transport. These conditions also allow for the employment of certain methods not available for other sites with more reactive contaminants. This paper describes the field conditions based on borehole logs, sediment samples, ground penetrating radar profiles and water sample analyses. These results are then implemented in establishing a 3-D numerical model, in order to test various scenarios for remediation of the PFOS-contaminated groundwater aquifer.

Field settings and characterisation of sediments

The infiltration-magazine from which the PFOS-contaminated water infiltrated the subsurface is situated 2-4m below the surface. The bottom of the infiltration-magazine is approximately 3m above the groundwater table, allowing 2-3m of vadose-zone infiltration before reaching the saturated zone at about 7m depth.

Ground penetrating radar (GPR) profiles and borehole sediment samples have shown the deposits below the infiltration-magazine to consist of glasiofluvial medium sand channel fill to a depth of c. 6m, below which medium sand delta foreset cross-bedding continues to approximately 8m depth, at which level the sediments become coarser, including gravely coarse sand cross-bedding. At approximately 16m depth the deposits show a transition to finer sediments, consisting of silt and clay rich fine sand. The delta foreset cross-bedding transition to horizontal delta bottomset beds appears to be between 16m and 22m below the surface.

The effective portion of the aquifer is considered to be above the fine sands at c. 16m depth and the groundwater table at c. 7m depth. Grain size analyses from several of the 17 monitoring boreholes indicate a saturated hydraulic conductivity ranging between $2*10^{-6}$ and $4*10^{-4}$ m/s in the 7-11m depth range (sample depths), and an average hydraulic conductivity of $1*10^{-4}$ m/s, based on the empirical equation by Gustafson (1986) and the 10^{th} and 60^{th} percentile grain size diameter. The conceptual hydrogeologic model showing the magazine and groundwater is illustrated in Figure 1.

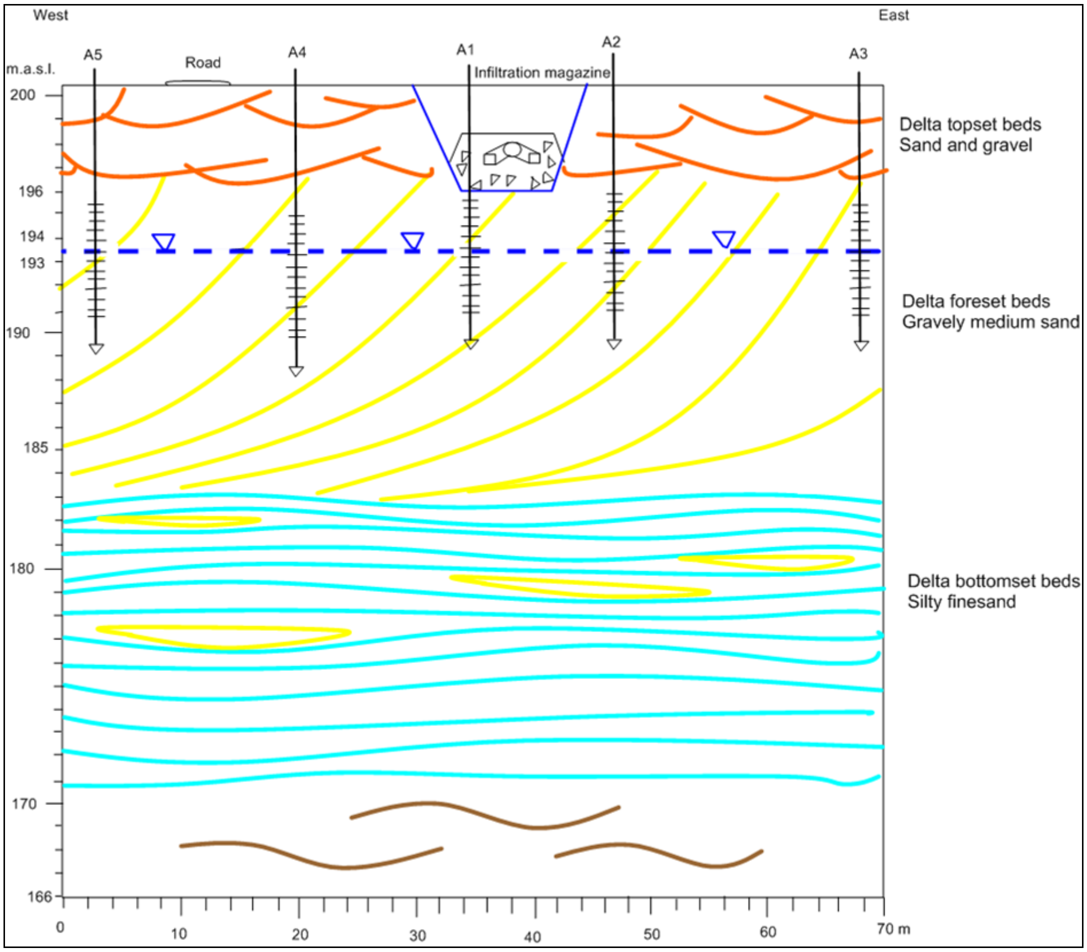

Figure 1. Conceptual hydrogeologic model, showing a west-east profile, including monitoring boreholes (A1-A5), the infiltration magazine and the groundwater table. The effective portion of the aquifer is considered to be above c. 184 m a.s.l.

Groundwater model

A 3-D numerical flow and transport model was established, using Visual-MODFLOW Pro. The 3-layer model contains the regional groundwater divide, railroad drainage section and groundwater seepage faces, local recharge within the airport area and the surface-water infiltration magazine. Hydrogeological properties from field investigations are implemented in the numerical model, with calibration to recent groundwater level measurements. Simulated transport pattern and rate coincide well with field monitoring.

The numerical model has been employed in simulating various remediation scenarios for an optimal remediation setup with one or more abstraction boreholes and re-infiltration points/ditches. The chosen remediation method for removing PFOS from the groundwater aquifer is to use an active carbon filter to rinse the groundwater to 300 ng/l before re-infiltrating the treated water back into the infiltration magazine to flush out the remaining PFOS. Re-infiltration has also been modelled on either side of the infiltration magazine in order to limit the lateral migration of PFOS during the infiltration, and to determine lateral re-infiltration sites and rates (see Figure 2).

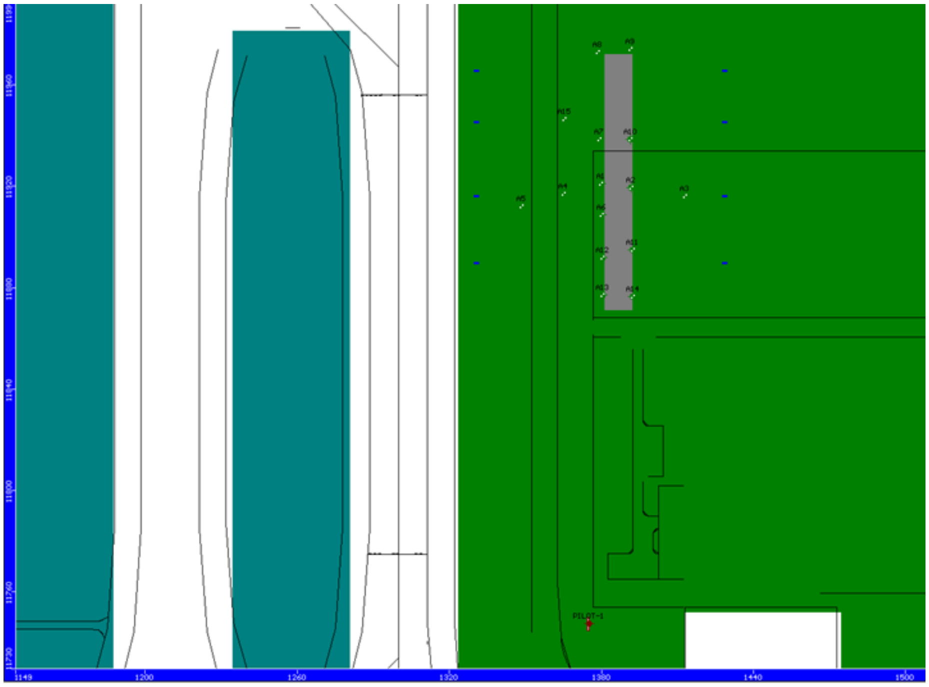

Figure 2. Remediation scenario with one abstraction borehole (Pilot-1), infiltration-magazine (grey rectangle), monitoring boreholes (A1-A15) and Control Re-infiltration Points (blue dashes, both sides of infiltration-magazine). Green, blue and white colour fields represent different surface recharge rates.

The remediation process should be conducted such that the least amount of uncontaminated groundwater is pumped up, limiting the amount of water passing through the active carbon filters. The groundwater drawdown near the abstraction borehole should be limited since PFOS has been found to have higher concentrations at the transition between the unsaturated and saturated zones. Simulation scenarios focused on limiting the number of boreholes and the pumping rate necessary to capture the majority of the PFOS-plume.

Results

After testing various scenarios, a single abstraction borehole with 4 Control Re-infiltration Points (red spots in figure 3) on either side of the infiltration magazine was most efficient in capturing the majority of the plume, and minimizing the amount of groundwater to be treated. This configuration was also conditioned on practical solutions in the field, including consideration of airport infrastructures and year-round operations. Borehole design was also a factor limiting abstraction rates. The pumping rate from the abstraction borehole in the scenario pictured below (Figure 3) is set at 1.5 l/s (129.6 m^3/d), where, after having been treated in the active carbon filter, the groundwater is re-infiltrated. 0.5 l/s (43.2 m^3/d) is directed to the infiltration-magazine and 0.5 l/s is infiltrated on either side of the infiltration-magazine, evenly distributed in 4 Control Re-infiltration Points on each side.

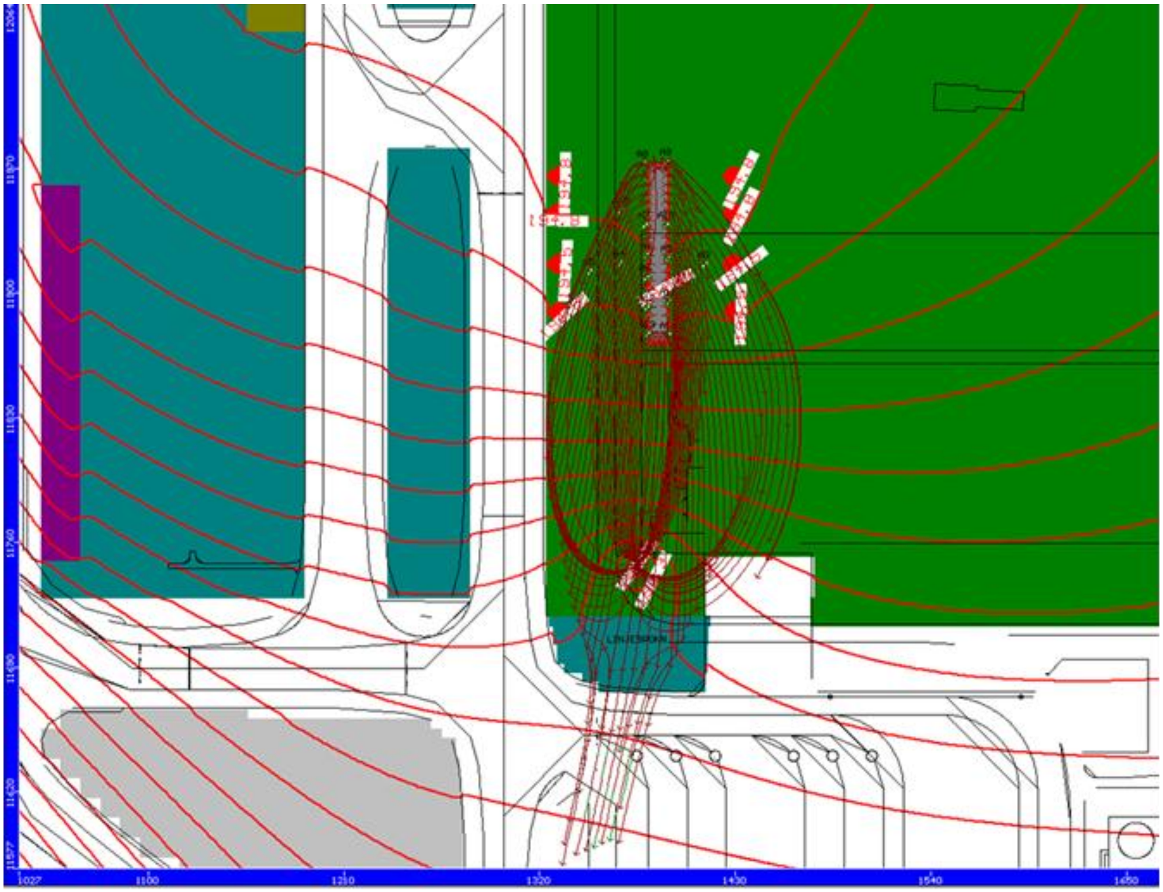

Figure 3. Simulation of PFOS transport and remediation with one abstraction borehole (ca. Y=11700) and re-infiltration in the infiltration-magazine (grey rectangle). Control re-infiltration points (red spots) on either side of infiltratrion-magazine. Simulated scenario 3 years after date of contaminant release, 1.5 years after abstraction from remediation borehole. Particle tracking illustrates groundwater velocities and advection transport.

Discussion

Field concentration measurements verify the contamination migration pattern illustrated in Figure 3. Initial breakthroughs of PFOS at monitoring boreholes also indicate very low distribution coefficients in these glaciofluvial sediments, supporting Kd-values of approximately 2-10 l/kg (Gellrich and Knepper, 2012). Considering the transport velocities recorded at the monitoring boreholes, groundwater remediation should be completed approximately 6 years after initiation. Additional boreholes may be added to the system to enhance and shorten recovery.

References

Ferry, M. and Wilson, J. T. 2009. Extent of sorption and biodegradability of perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS) in aquifer sediment (Maryland). Abstract from 10th International In Situ and On-site bioremediation symposium. EPA Science Inventory. Baltimore MD, May 05-08, 2009.

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