Thermal Treatment of Thick Peat Layers – DNAPL Removal and Shrinkage

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ABSTRACT

A PCE DNAPL source zone was treated using thermal conduction heating combined with multi-phase extraction. Thick peat layers, even when contaminated with PCE DNAPL, were remediated to average soil PCE concentrations of 0.17 mg/kg (99.6% reduction compared to starting levels). This was accomplished in 83 days of heating, by elevating the temperature to the boiling point of water, and by boiling a fraction of the pore water (approximately 27%). Substantial subsidence was observed due to shrinkage of the peat. Therefore, special caution must be used during thermal treatment of sites underlain by organic-rich deposits.

INTRODUCTION

Peat layers are abundant in certain geological settings and constitute a special remedial challenge. The high content of organic matter makes sorption a dominant retardation factor, trapping the organic contaminants in a manner similar to adsorption onto activated charcoal. This poses a challenge for any remedial approach based on physical removal of the contamination. Laboratory results on thermal treatment of such layers have shown great promise – PCE removal was achieved at the boiling point of water.

If peat layers are remediated, partial desaturation can lead to oxidation and shrinkage, as the organic matter is exposed to oxygen. This potentially can result in acid conditions if pyrite (FeS_2) is present and oxidized into sulfuric acid. The oxidation and removal of mass can affect the geotechnical stability of the site, as peat layers may shrink and the surface subside. This may limit the applicability of aggressive source removal technologies such as thermal methods. This paper presents a full-scale thermal remediation application to a site with thick peat zones.

SITE DESCRIPTION AND ISTD DESIGN

The Skuldelev site in Denmark had a 7 m (23 ft) deep PCE DNAPL source zone located directly adjacent to a building. Sewer leakage had resulted in the DNAPL release. The site is situated in a wetland area, adjacent to a fire pond. Figure 1 depicts a conceptual cross-section of the treatment area. Part of the source area contained an up to 2.3 m (7.5 ft) thick peat layer located near the water table. High PCE concentrations were measured in the peat and the groundwater flowing through it.

Previous remedial efforts at the site had lead to the recovery of ~1,500 liters of PCE DNAPL using simple liquid pumping, but a substantial mass of PCE was still in place (NIRAS A/S 2005). A small ISTD pilot test conducted in 2006 proved that the site materials could be heated, and provided important design data for full-scale thermal remediation (Krüger 2007). Based on the pilot test, it was determined that hydraulic isolation of the source area was necessary for effective heating and remediation.

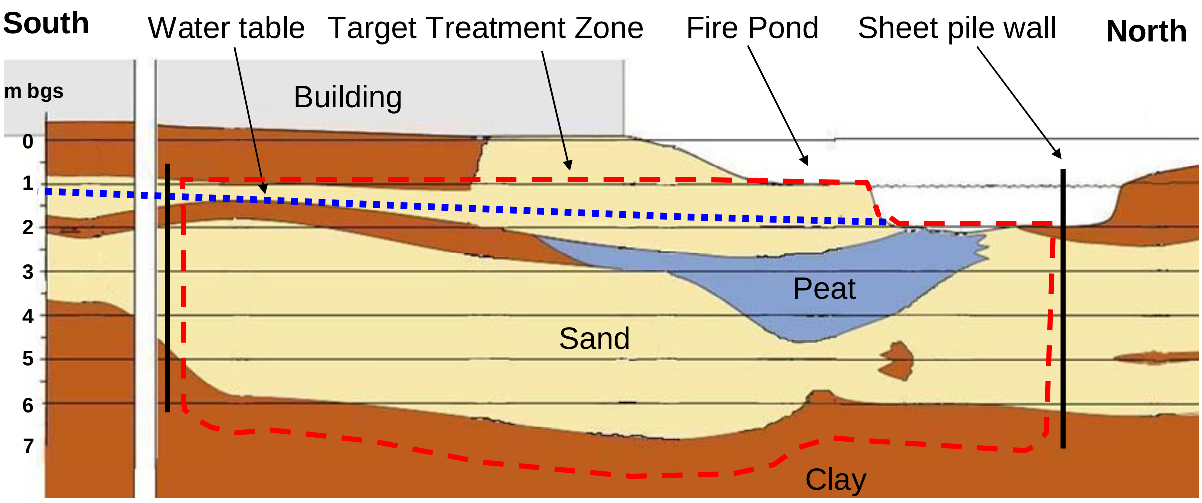

Figure 1. Conceptual Treatment Area Cross-Section.

First, the fire pond was emptied and the groundwater table lowered to allow for work in the wetland area. The DNAPL source zone was isolated by installation of metal sheet piles then treated thermally at 100°C using In-Situ Thermal Desorption (ISTD), also known as Thermal Conductive Heating.

Figure 2 shows the treatment area with the adjacent building in the background and the fire pond in the foreground. The total area and volume within the sheet pile wall was 260 m^2 (2,800 ft^2) and 1,695 m^3 (2,220 cy), respectively. Heat was supplied by 53 ISTD borings. Mobilized contamination was captured by 21 vacuum extraction wells, and three groundwater extraction wells.

Figure 2. Treatment Area During Operation.

Extracted vapors were cooled and treated by granular activated carbon. Due to a natural sloping terrain in the treatment area, the area was divided into four horizontal levels (the elevation changes are visible in Figure 2). The thermal treatment involved partial dewatering of the peat layers, as steam formation and extraction lowered the water table inside the isolated source area.

RESULTS

The thermal system was turned on September 20 2008. The thermal remedy was completed December 22 2008 after 83 days of heating and 11 days of post treatment vapor extraction. The heat input was decreased November 29 to prepare for soil sampling. At that point the average temperature in the treatment area was 103 °C. Figure 3 shows the temperature profile at temperature monitoring well T12 from startup and until right before the heat was terminated. T12 was located in an area with up to 2 meter of peat and sandy peat.

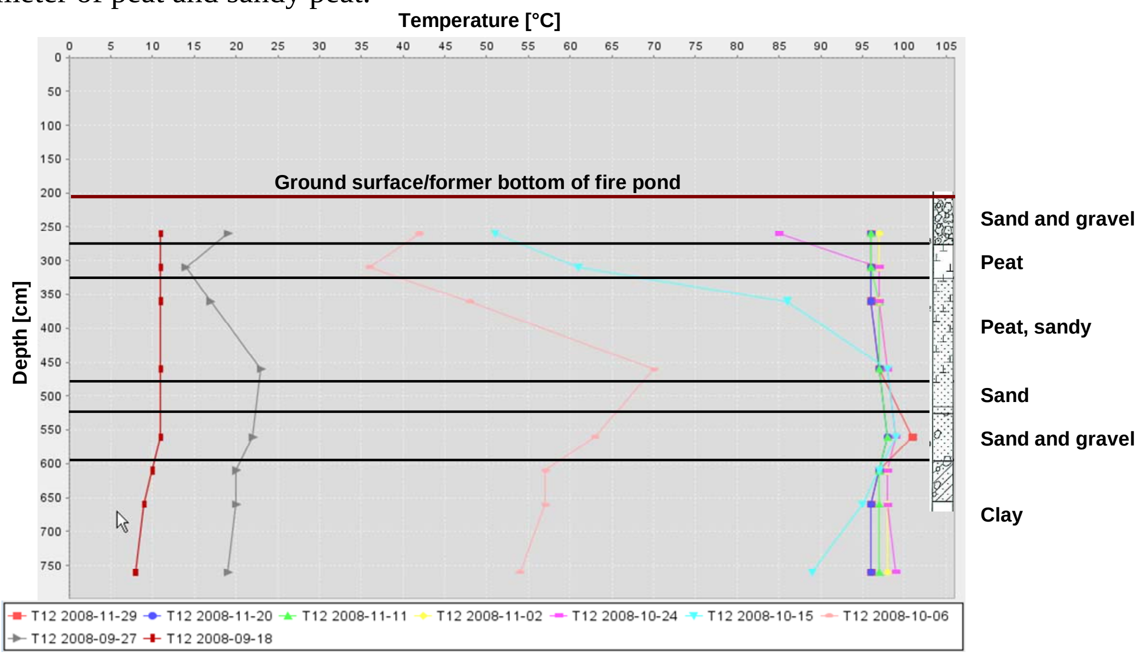

Figure 3. Temperature Profile at T12 Located in Peat Area.

The site heated relatively uniformly from top to bottom, without any significant difficulty of heating the peat zones. After successful heating to the boiling point and removal of a substantial PCE mass, the site was partially cooled and sampled. An estimated 410 kg (900 lbs) of contaminants were removed during treatment.

Before thermal treatment, 46 soil samples were collected in the Target Treatment Zone (TTZ) to document the soil concentrations within the treatment area. The sample results and following SUDAN IV tests on the samples indicated the presence of a substantial DNAPL mass in the treatment area. Average pre treatment soil concentrations were 128 mg PCE/kg.

After thermal treatment, 86 soils samples were collected to document the remediation efficiency. The average post treatment PCE concentration was 0.13 mg/kg. The highest post treatment soil concentration of 5.2 mg PCE/kg was detected in a topsoil sample collected 0.75 (2 ft) below grade. Figure 4 shows the post and pre treatment soils concentrations for all samples collected at the site while Figure 5 shows concentrations for peat samples only.

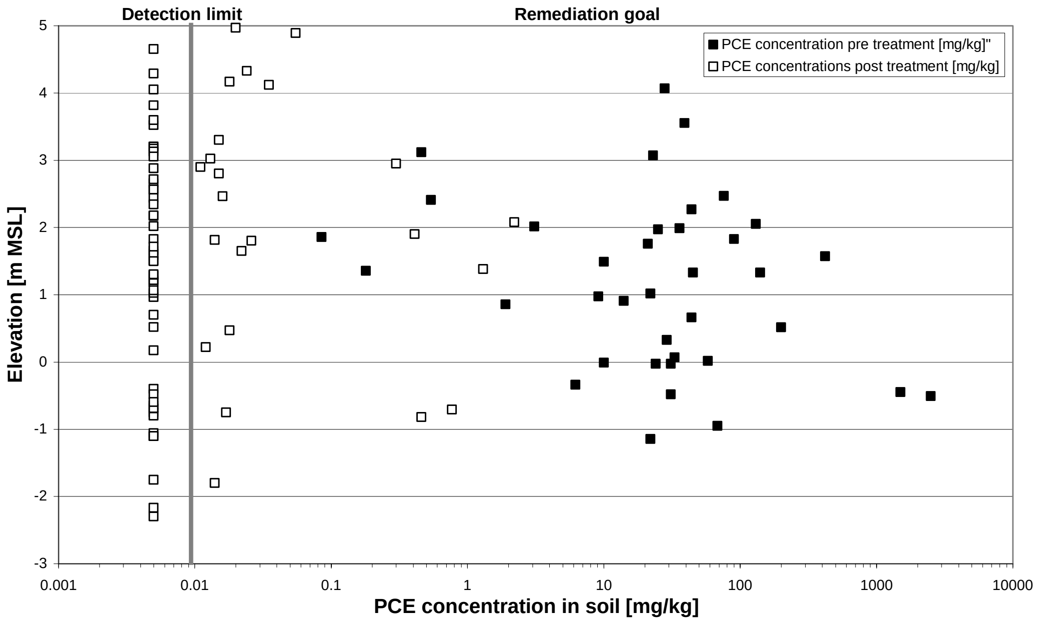

Figure 4. Pre and Post Treatment Soil PCE Concentrations with Depth Relative to the Mean Sea Level (MSL). Note that the X-axis is Logarithmic. Non-Detect Samples are Shown in the Graph with a Value Corresponding to Half the Analytical Detection Limit.

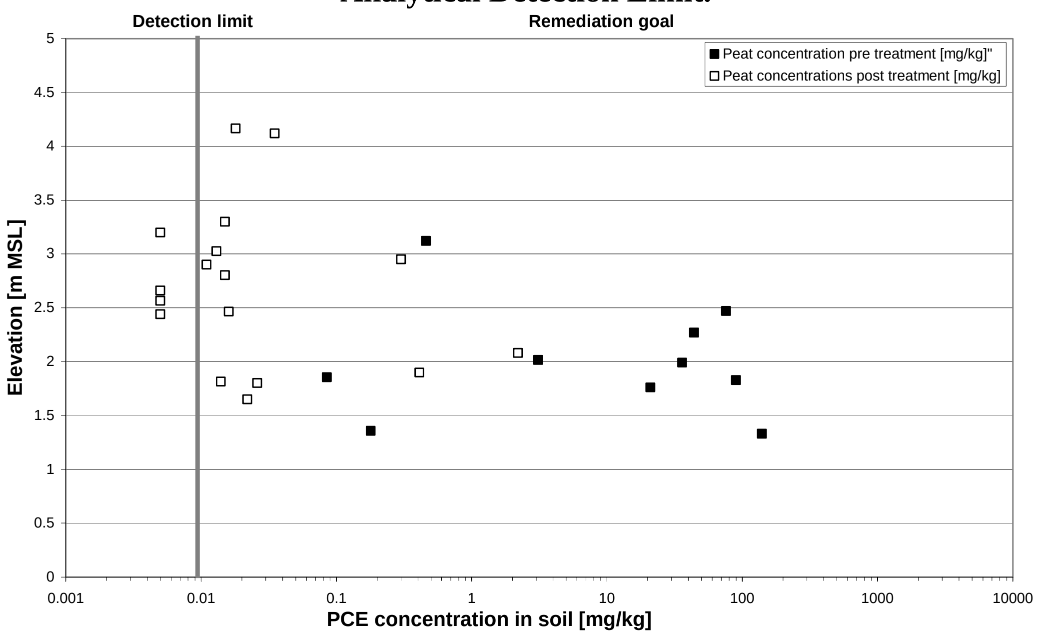

Figure 5. Pre and Post Treatment Soil PCE Concentrations with Depth Relative to the Mean Sea Level for Peat Samples. Note that the X-axis is Logarithmic. Non-Detect Samples are Shown in the Graph with a Value Corresponding to Half the Analytical Detection Limit.

Out of 46 pre-treatment and 86 post-treatment samples, 10 and 18 respectively were collected in peat. The average pre-treatment soil concentration in the high organic samples was 41 mg/kg while the average post-treatment soil concentration was 0.17 mg/kg. The highest post-treatment peat concentration was 2.2 mg PCE/kg.

The average remediation efficiency was found to be 99.9 % for all samples collected. For peat samples the average remediation efficiency was 99.6 %. All post-treatment soil concentrations were below the remediation goal of 5-10 mg PCE/kg.

During operation, the soil was partially dried out in the treatment area. Water was pumped and removed inside of the sheet pile wall causing the soil to drain. Then, the ISTD treatment caused most of the treatment volume to boil, causing the soil water content to decrease due to evaporation.

Figure 6 shows the soil water content prior to and after treatment. The water content was obtained from 37 samples pre treatment and 80 sample post treatment.

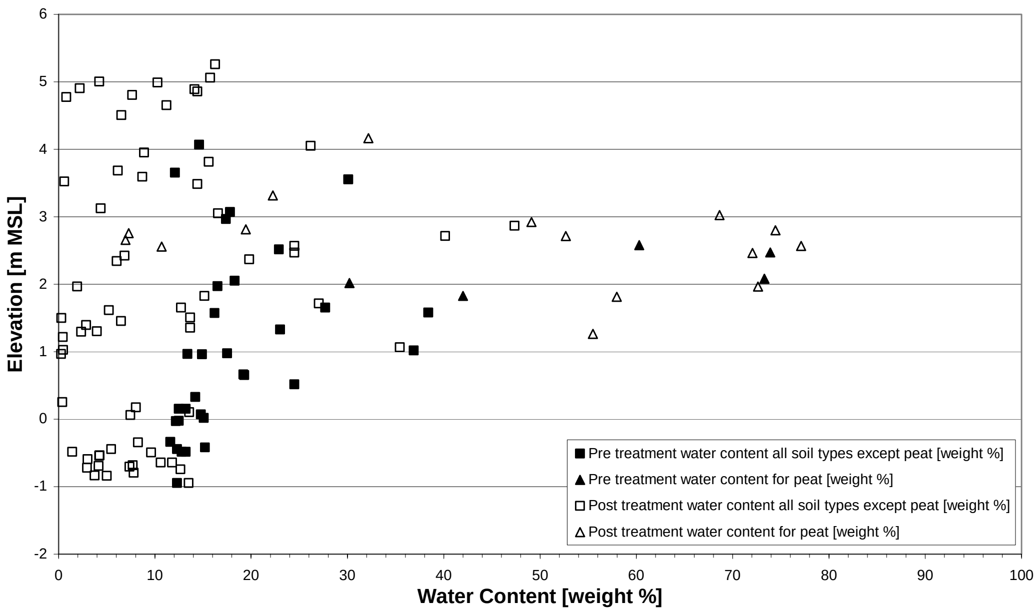

Figure 6. Soil Water Content Prior to and After Treatment by Depth Relative to the Mean Sea Level.

During typical ISTD implementations for PCE, a water quantity equivalent to between 20 and 40 % of the pore volume is expected to be removed and extracted as steam. The average water content in the untreated soil at the site was 23.0 % by weight while the average water content post treatment was 16.9% by weight, corresponding to a removal of 27% of the pore water originally present in the soil. The water content in peat layers was obtained for 5 and 15 samples pre and post treatment respectively. The average post treatment peat water content was 56 % by weight while the average post treatment water content was 45 % by weight. On average 19 % of the peat pore water has been removed during treatment. Therefore, the presence of the peat layer did not markedly delay the thermal treatment or lead to excessive energy demands.

The peat layers were remediated to satisfactory levels, but subsidence was obvious during treatment, as measured using twelve monitoring points placed inside the sheet pile wall. Nine of the monitoring points were placed directly on the surface cover (Point 201-209). The remaining three monitoring points were mounted on a plate and buried 0.7 m (~2 ft) below the surface cover, only letting the top of the monitoring rod stick up above the surface cover (point 210-212). Figure 7 shows the location of each of the 12 monitoring points.

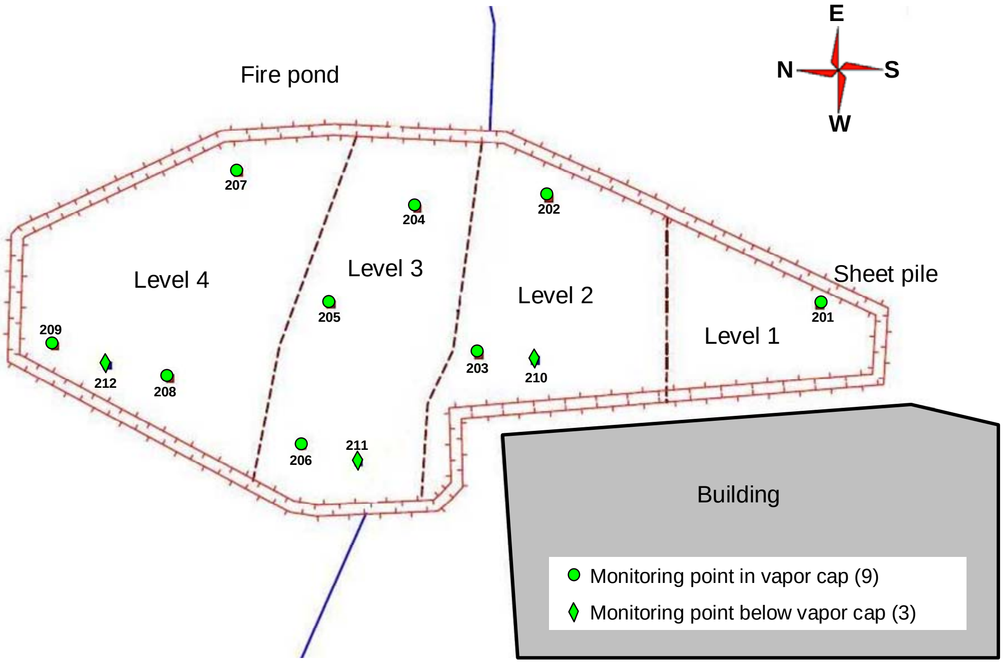

Figure 7. Location of 12 Leveling Points Used to Measure Subsidence During Treatment.

An accurate survey was made prior to start of operation (September 8 2009) and again after 1 month of operation (October 17 2008). The surface cover was insulated in November 2008 and all monitoring points were covered by the additional insulation not allowing any measurements conducted until after shutdown of the thermal system. The points were measured the last time on December 17 2008, near the end of the thermal operations. The results from the three monitoring rounds are shown in Figure 8.

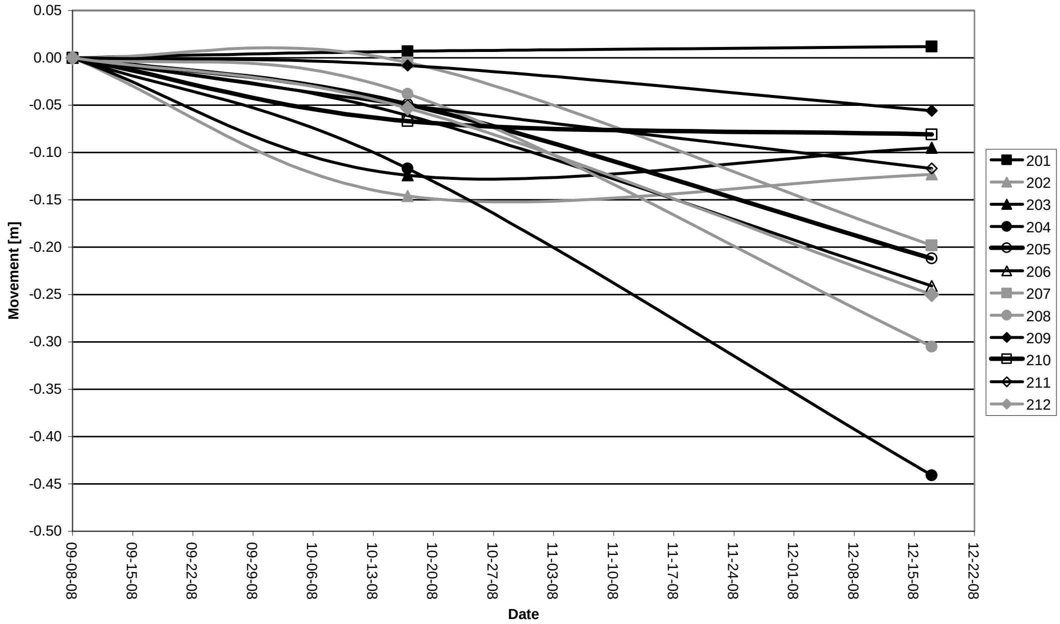

Figure 8. Surveyed levels for the 12 locations during ISTD treatment.

Table 1 shows a summary of the observed movements during treatment. Positive numbers indicate rising and negative numbers indicate subsidence.

Table 1. Maximum Peat Layer Depth and Maximum, Minimum and Average Movement on Each of the 4 Levels in the Treatment Area.

Location in treatment area	Monitoring points	Max. peat layer depth [m]	Max. movement [m]	Min. movement [m]	Average movement [m]
Level 1	Point 201	No peat	0.012		0.012
Level 2	Point 202-203 and 210	0.6	-0.121	-0.081	-0.100
Level 3	Point 204-206 and 211	2.3	-0.441	-0.117	-0.253
Level 4	Point 207-209 and 212	1.9	-0.305	-0.056	-0.202

All areas with peat subsided during the thermal treatment which included dewatering. The maximum subsidence was observed on level 3, where peat layers as thick as 2.3 m (7.5 ft) were observed. The subsidence was as high as 0.441 m (1.4 ft). The major subsidence in certain areas caused the light-weight concrete surface cover to crack and move, and frequent cover repair was required to ensure vapor capture and to avoid odor problems. No substantial effect on the adjacent building caused by the thermal remediation was observed.

In the only area where peat has not been observed (level 1) only minor movements were recorded. This is consistent with the lessons learned from another Danish thermal project located near Odense, Denmark, where subsidence were monitored during remediation from 18 monitoring points. The site was heated to 14 m depth by a combination of ISTD and steam injection, and subsided 0.003 m calculated as an average of the 18 monitoring points (Skou et al. 2009; Ploug 2010). The geology at the site was dominated by a 10 meter thick clay layer located on top of a thick sand layer. No peat layers were present.

After completion of the thermal source removal, the site was re-graded and restored to original conditions. The fire pond was allowed to re-fill, and the local community now has their idyllic town center back, with picnic areas and wildlife restored.

DISCUSSION

The empirical evidence shows that thick, organic-rich layers, when heated and exposed to oxygen, can shrink and lead to subsidence. This will be particularly important when the peat layers consist of organic grains/structural elements that comprise the pore structure by grain-to-grain contact. Loss of mass by oxidation will then cause a loss of solids volume. In other cases, where small peat fragments are present within load-bearing quartz sediment, significant subsidence may not occur despite partial oxidation of a significant amount of organic material. An example of such a site is presented in Paper 384 in this volume (Heron et al. 2010).

For thermal treatment at sites with peat, it is important to understand the peat structure, location, and role for the geotechnical properties of the subsurface. At sites where subsidence is expected due to potential oxidation of the peat, a careful geotechnical review must be completed. In some instances, foundations may have to be reinforced. However, most buildings built on peat-rich deposits are founded on piles driven to depths below the peat, and will not be significantly impacted by the thermal treatment.

CONCLUSIONS

This full-scale ISTD implementation showed that thick peat layers, even when contaminated with PCE DNAPL, can be remediated to soil concentrations as low as 0.17 mg/kg (average of all peat samples). This was accomplished in 83 days of heating, by elevating the temperature to the boiling point of water, and by boiling a fraction of the pore water. Substantial subsidence may be expected where thick peat layers are heated and partially dewatered. Therefore, special caution must be used during thermal treatment of sites underlain by organic-rich deposits.

REFERENCES

Heron, G., LaChance, J., Bierschenk, J., Parker, K., Vinci, S., Woodmansee, R. and Schneider, J. 2010. *Combining Thermal Treatment with MNA at a Brownfield DNAPL Site.* Paper 384 in: Remediation of Chlorinated and Recalcitrant Compounds—2010. Proceedings of the seventh International Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, CA; May 2010).

Krüger. 2007. *Capital Region of Denmark, ISTD Pilot Test, Vestergade 5, Skuldelev*, February 2007 (Report in Danish).

NIRAS A/S. 2005. *Frederiksborg County. Vestergade 5, Skuldelev. Evaluation and Clean-Up of DNAPL at Well KB15*. Minute October 24 2005. (Minute in Danish).

Ploug, N., Holm, J. ,Jensen, P., Steffensen, H. Nielsen, S. G., Heron, G. 2010. *Thermal treatment – How Close Can You Go and is it Save to Humans.* Paper in: Remediation of Chlorinated and Recalcitrant Compounds—2010. Proceedings of the seventh International Conference on Remediation of Chlorinated and Recalcitrant Compounds (Monterey, CA; May 2010).

Skou, H., Just, N., Steffensen, H., Heron, G. and Griepke Nielsen, S. Remediation *of PCE Contamination by a Combination of ISTD and Steam Enhanced Extraction, Knullen 8, Odense, Denmark*. Paper in "Proceedings for Winter meeting 2009, ATV Committee for Soil and Groundwater (9.-11. March 2009)" (Paper in Danish).