Remediation of Groundwater Pollution at a Former Gas Works Site by *in-situ* Methods

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INTRODUCTION

At a former Danish gas works, the structures and the heavily contaminated soils have been removed leaving diffuse groundwater pollution and soil contamination with tars and cyanides to a depth of over 10 m. An *in-situ* remediation effort has been established with the aim of reducing future risks to human health and to prevent further pollution of the groundwater reservoir. The remediation method is based on a low energy and low cost method. The objective is that the site can be utilised for town development projects within a realistic time-frame. The remediation is jointly financed by the municipal authorities, Hjørring, Denmark, who own the site and the Danish Environmental Protection Agency.

THE REMEDIATION CONCEPT

Groundwater is pumped up, aerated and filtered to remove iron, and then reinfiltrated over the contaminated soil which covers an area of 8 000 m^2.

The objective is to enhance and optimise the natural biological degradation processes that occur in the soil and groundwater by:

- increasing infiltration and leaching of the water soluble tar components in the soil layers; and
- increasing oxidation capacity in the soil and in groundwater by infiltration of aerated water.

The infiltration plant is coved by 1 m of uncontaminated soil and sowed with grass, so that no contact to the contaminated soil can occur. Furthermore, the infiltration plant acts as a capillary barrier to the upward transport of contaminants.

THE INFILTRATION PLANT

The infiltration plant is designed to pump groundwater from the former gas works supply water well, which is just outside the infiltration area. After treatment in a traditional water treatment plant to aerate the water and remove iron by means of a sand filter, the water is infiltrated over the contaminated soil. In the treatment plant, two dosing units are available for addition of micronutrients or additional oxidation agents such as nitrate. From the treatment plant, the water is pumped to eight distribution wells, which supply eight sections of the infiltration plant. The distribution of water to the eight different sections can be controlled by manual adjustment of values in the distribution wells. In each section, the water passes through a 15 cm gravel/stone layer and percolates to the undisturbed soil layers.

OPERATION

The plant was put into operation in June of 1993 with a water flow of 29 m^3/h. After one month, the water flow was altered to stop/start flow with a frequency of 84 hours to establish an intermittent infiltration to create alternating aerated and water saturated zones down through the soil layers. After 13 months of operation, the plant was again adjusted to a three-week stop/start frequency, so that water is infiltrated over a period of one week, and then, for a period of two weeks, no infiltration occurs. The cycle is then repeated. This change was initiated because the result of an investigation of the content of oxygen, carbon dioxide and methane in the soil air showed that in the contaminated infiltration area, no appreciable oxygen content could be demonstrated in the soil air. The change in stop/start operation changes the infiltration rate from about 16 000 mm/year to about 9 000 mm/year. In comparison, the total precipitation in this area is about 300–350 mm/year. The average infiltration through the soil layers has thus been increased by a factor 30 in comparison with normal conditions, but the actual rate is up to three times greater in periods with infiltration.

After about one year of operation (13 months), 50 – 60 mg/l of nitrate, in the form of sodium nitrate, was added to the water. The objective is to try and increase the nitrate content in those parts of the reservoir, which are nitrate deficient and to study the effects of nitrate addition. In the most contaminated part of the reservoir, nitrate is present in large quantities, so nitrate addition is not strictly required to aid biological degradation.

MONITORING WELLS

Ten wells are placed around and within the infiltration area to document the efficiency of the remediation by measurement of the chemical and biological composition of water samples during the course of the project. The groundwater level is 8 – 11 m under the terrain. Changes in the absolute and relative concentrations of the various chemical components in the groundwater have been noted, which reflect the enhanced leaching of pollutants and the biological degradation of the most labile components. These wells are spread over the infiltration area and with two wells up-stream to control background conditions and two wells downstream. The wells are screened at different depths in the groundwater aquifer to enable observation of degradation or other changes as a function of depth in the aquifer.

CHANGES IN GROUNDWATER CHEMISTRY DURING INFILTRATION

The initial analysis of groundwater samples after clean-up of the hotspots and establishment of the infiltration plant revealed that only water samples from one of the ten monitoring wells were polluted to any great extent. Most water samples were, however, deficient in oxygen and nitrate.

The infiltration water is not polluted with organic tar components, but contains an appreciable amount of chloride, sulphate and bicarbonate ions indicating a source of pollution from the gas works. Before distribution to the distribution wells, the infiltration water has a typical oxygen content of about 1.5 – 4 mg/l. Aeration of the water occurs in the distribution well so that the oxygen content in the infiltration water is typically 7 – 8 mg/l. The original nitrate content in the infiltration water was 20 mg/l, before addition of 50 mg nitrate/l in the form of sodium nitrate. The original sodium content was about 70 mg/l and is now about 97 mg/l due to the addition of nitrate.

During the last 20 months, many of the samples from the ten sampling wells have shown an increase in oxygen and nitrate content, but the increase in nitrate can be related to oxidation of ammonium to nitrate. For example, in the most polluted well, the initial concentration of 120 mg ammonium/l has fallen to an insignificant level, while the initial concentration has risen to 429 mg nitrate/l. The concentration is now falling, presumably due to dilution effects.

The most polluted well has shown a number of interesting changes in the relative concentrations of pollutants. The sulphate, bicarbonate and chloride content has increased appreciably, indicating pollution from the gas works. The oxygen content in the groundwater has been stable and is about 0.2 – 0.4 mg/l, while the cyanide content is about 0.5 – 0.7 mg/l. Figure 1 shows the changes in concentration of organic tar components over the course of the last 20 months.

As is apparent from Figure 1, a fall in concentration is seen over the course of the first six months. The concentrations of all components then increase, and the increase is most pronounced for benzene, the methylphenols and dimethylphenols and least for the alkyl benzenes such as toluene, xylenes, etc. An increase in the content of other tar components such as the PAHs (methylnaphthalene and fluorene) of up to 13 µg/l and NSO-compounds (benzothiophene and carbazole) of up to 33 µg/l is seen after 20 months.

No significant changes at the other monitoring wells downstream or in the recirculated water from the well which supplies the water to the infiltration plant have been observed. Water samples from the contaminated well taken at greater depths in the aquifer show an increase in ammonium content as well as the organic tar components which indicate that the contaminated water is pressed down by the pressure of the infiltrating water.

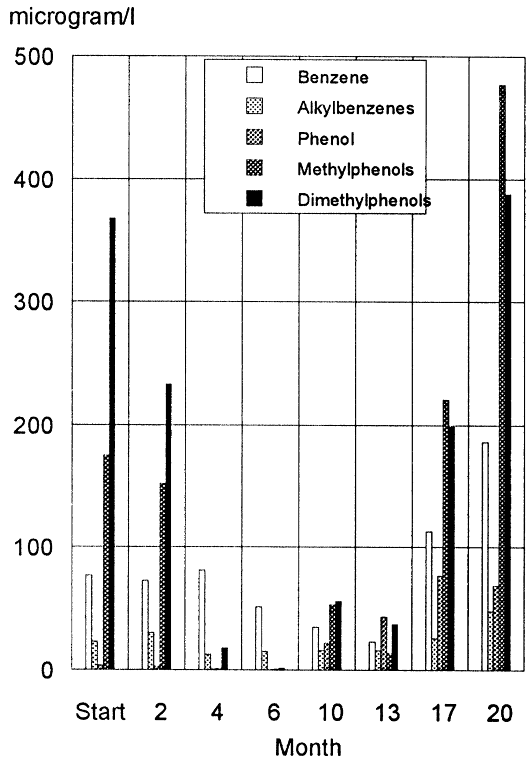

Figure 1. Changes in concentration with time

CONCLUSIONS CONCERNING CLEAN-UP OF THE SOIL POLLUTION

The results of the measurements of soil air and the groundwater measurements indicate that aerobic biological degradation of tar components occurs. The increase in concentration in the groundwater samples with time indicates that a stable equilibrium between leaching of the tar components and biological degradation is not achieved as yet. The soil air measurements have, however, indicated that the oxygen content is very low in the soil in comparison with reference measurements just outside the contaminated area, which indicates that the aerobic biological degradation in the soil is not optimal. It should be noted that bacteria often survive and prosper in biofilms on the surface of the soil particles and can utilise the very small amounts of oxygen present, by active uptake. Oxygen can also be utilised directly from the percolating water, which initially has a content of 6–8 mg/l. Furthermore, the infiltration water has a high content of an alternative oxidation agent in the form of nitrate. It is assessed, therefore, that a good potential for aerobic degradation exists in the soil layers, even although it has not been possible to introduce measurable amounts of air into the soil.

CONCLUSIONS CONCERNING GROUNDWATER POLLUTION

The infiltration plant has shifted the natural redox conditions (as indicated by the ammonium/nitrate ratio and oxygen level) in the groundwater toward a more aerobic system.

The chemical analyses of groundwater samples from the monitoring wells over a period of 20 months have shown that tar pollution in the groundwater is restricted to a zone around the most contaminated well. The pollution is not found in the monitoring wells downstream, presumably due to the fact that the pollution is biologically degraded in the groundwater within a relatively restricted zone. The pollution levels in groundwater in this zone have increased about 2 – 3 times above the initial level and the pollution is also forced to greater depths in the aquifer in this zone due to the pressure of the infiltration. It should be noted that at the start it was the tar components that are resistant to biological degradation that were dominant in the groundwater, but now the more easily degraded monoalkylphenols and the labile phenol are also present in large amounts, which indicates an increased leaching of tar components from the soil.

The groundwater flow pattern has been altered due to the cone of depression of the pumping well so that the pumping well and one other monitoring well lie in the path of any transport of pollution away from the polluted zone.

ADDITIONAL WORK

No major changes of operation are planned for the remainder of the trial period which extends to the end of 1995. Three additional intensive monitoring rounds are planned, especially where the polluted well and the wells downstream, including the pumping well, are located.