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Environmental Risk Assessment, The Spatial Distribution of PHC in Quaternary Sediments beneath Fuel Stations and Bulk Fuel Storage Sites

Abstract

The capacity for petroleum hydrocarbons (PHC1)) to migrate through soil is often over-estimated. This is valid for both the aerobic zone as well as for groundwater bearing strata. The evaluation of more than 400 audits, which were made for fuel stations and bulk fuel storage sites in Central and Northern Germany during the mid nineties of the last century proves the limited expansion of PHC, even when measured locally in high concentrations.
The relatively small ability of PHC to migrate through clastic sediments can be proven through evaluation of various survey results on the actual contamination of fuel stations and bulk fuel storage sites and also by thorough evaluation of concentrations of PHC measured at various depths of cores from drilling campaigns. It also can be demonstrated by the use of exploration wells to evaluate concentrations of PHC in groundwater.
Such wells were installed along the site boundaries of fuel stations and storage sites to measure migration of PHC which had been detected in central areas of the sites in higher concentrations. All reported data confirm that migration of PHC through clastic sediments over distances exceeding some decametres is highly improbable.
Unrealistic assumptions of PHC migration in soil could be the result of simply applying the "Darcy-Law", which is valid for water within double- or multiple-phase flow-systems in the subsoil. Other reasons could be non-representative sampling methods or the extrapolation of single, sometimes extremely high analytical results, to reflect the average level of PHC-contamination on surveyed sites.
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1 Introduction

In order to gather evidence on the potential state of contamination with PHC, more than 400 fuel stations and bulk fuel storage sites in Germanywere audited in the mid 1990's. The audits were well documented in standardised reports in order to facilitate comparability of results between the various locations. Because the audits were performed throughout all areas of central and northern Germany, the influence of PHC-contamination on all possible (hydro-) geological environments were covered.
In evaluating potentially contaminated sites different methodical approaches are possible.
The method used in said audits was completed following an internal procedure designed by the "Environmental Department" of the "Treuhandanstalt" (environmental department of the former fiduciary authority to convert the economy of the former GDR to the free market).
In brief, this method relates any contamination detected to the possibility of endangering exposed nearby groundwater resources or other fields of public interest, such as human health. In order to give a prognosis regarding the likelihood of remedial action on the part of the relevant landowner, an opinion is expressed in the audit report as to the probability of legal recourse or other remedial actions [1].
Such prognoses, not only for fuel stations but also for all other asset disposals handled by the "Treuhandanstalt", were essential in both valuing the disposals and securing investors for a large numbers of state assets.
When the audits were performed the environmental legislation in Germany was mainly focused on the protection of groundwater resources. This was enhanced in 1998 with the "Lawfor the Protection of Soil" [2].
It is possible to apply the stated method of analysing environmental risk to current German legislation. Again in brief, the 1998 act defines an environmental damage as a "harmful alteration of the soil". Contemporary opinions have to accurately predict or assess the extent to which "alterations of soil" are "harmful" or potentially hazardous to the environment or other fields of public interest.

2 Hot Spots for Contamination at Fuel Stations and Bulk Fuel Storage Sites

In general fuel stations have one or more filling locations. These locations, where the actual process of filling takes place utilising underground tanks and pipelines, represent the areas where contamination can be expected. Tanks above ground were the exception at the audited fuel stations.
As shown in Figure 1 the underground installations at fuel stations are quite complex and therefore susceptible to technical faults.
Fuel stations are sealed around the filling areas with different pavement materials. Quite often, these do not completely prevent the intrusion of PHC into the ground. Contamination in these areas happens due to equipment leakages and PHC dripping from the pump nozzles. PHC pumps often lead to contamination of the aerobic zone but in most cases do not penetrate deeper. - This means that leakages from the underground technical installations are more relevant to contamination of soil and groundwater.

The bedding of the tanks is in most cases coarse grained and permeable for PHC. Undetected leakages underground over a long period of time can lead to severe but local contamination of the groundwater nearby.
On bulk fuel storage sites contamination occurs almost exclusively around the filling locations above ground. Underground tanks were the exception at the sites surveyed. Because of the larger quantities of PHC handled at storage sites, the degree of contamination is often higher than at fuel stations.
Another reason for exceptionally high contamination levels was PHC-spillage as a consequence of warfare impacts during WorldWar II.

3 Characterisation of the (Hydro-)Geological Environments

Because fuel stations are widely distributed the whole variety of possible (hydro-) geological configurations in Germany were surveyed in the course of the audits.

3.1 Geology / pedology

"Except for cliffs of solid rock and steep mountain slopes, entire Central Europe (more than 90%) is covered by quaternary sediments" (Eissmann et al., 1994). Therefore, quaternary sediments also comprise the foundation area of most fuel stations and storage sites. The foundation of fuel stations and fuel storage sites is always made up of clastic sediments or sediment-like material.
There has been no evidence to suggest that solid rock has been the construction ground for any of the surveyed sites. Consequently, there have been no reports of contaminated groundwater that circulates within the fissures of solid rock formations.
"Soil" in this report is defined as foundation respectively building ground, which consists of clastic sediments or the weathered cover of solid rock. For the evaluation of the audits for each site the predominant type of soil described in each report was extrapolated over the entire site so that existing anomalies within the subsoil where neglected.

3.2 Hydrogeology

"Groundwater" is defined as underground water that fills out the pores of sediments or the fissures of solid rock completely and migrates due to the force of gravity.
For the statistical evaluation in this report four classes of groundwater occurrences have been defined (ground water ¡Ü2 m below surface, >2-4 m b. sur., >4-6 m b. sur., >6 m b. sur.).
The type of groundwater, which appears erratically underground and has only local extension does not function as an adequate conductor for contamination. This is often the case in dense sediments, which conduct groundwater poorly and in sediments on the slopes of hills and mountains. Such occurrences of groundwater were classified deeper (>) than 6 m.
Audits, in which the moisture of the soil was interpreted as groundwater, were also put into the class >6 m. Such a "groundwater" should not be used for the prediction of hazards through PHC-contamination because it cannot function as a conductor for contamination.
As a distinction between "genuine" groundwater, as it was defined at the beginning of this chapter and the moisture of soil the possibility of gaining representative samples from the observation wells could be taken.
Samples, which represent the average status of groundwater contamination should be taken out of a continuous stream of water pumped from the gauges. This is impossible from local groundwater occurrences and subsoil, which is merely moist.

4 The Classification of the Audited Sites

4.1 Audit parameters (Classes of the Risk for Liabilities - CR)

CR 1: no risk for the owner of the site recognized.
CR 2: minor risk recognized due to trace or moderate contamination being detected.
Legal recourse against the landowner is not considered high.
CR 3: high risk recognized due to distinct contamination being detected. Legal recourse against the landowner of the site is possible if not likely.
CR 4: very high risk due to extreme contamination being detected. Legal recourse can be taken for sure.
For the following evaluation of the audits the original scope of the data (471 sites) was reduced to 425 sites, since some of the sites had been both, fuel stations and storage sites or were situated very close together. Such objectswere therefore combined or removed from the data-pool. Only Table 2 includes all audited objects.

4.2 The distribution of the classes of risk (CR) in the audits

In relation to the above mentioned classification the following statistics can be given for 471 evaluated sites:
For a small number of cases (2%) the audit concluded that there was a very high probability of legal recourse against the landowner (CR 4). For nearly one third of all cases (28%) the audit concluded that there was a high probability for legal recourse (CR 3). For about two thirds of all cases (68%) the audit concluded that there was little chance of legal recourse, although moderate contaminationwas detected (CR 2). For only few cases (2%) the audit concluded that there was no risk of legal recourse at all (CR1).

5 Evaluation of the Measured Distances of "Groundwater to Surface" with Regard to the Classes of Risk

For the statistical evaluation of the sites' distances of "groundwater to the surface", the different distances, measured in the

various observation wells on the sites, were combined to a mean value and taken as one average "groundwater to the surface" distance per object (Table 1).
54 sites (13%) were built at locations with a groundwater distance ¡Ü2 m. These sites are mostly situated close to rivers or other such areas with a permanent influence of the groundwater on the technical installations underground. Possible PHC leakages from above the surface area have to pass only through a small layer of soil before reaching the first groundwater level.
Groundwater close to the surface had obviously no influence on the class of risk,which the auditors assigned to such sites within this class of groundwater distance. The statistical distribution of the range of groundwater distance ¡Ü2 mis the same as shown in the Table 2, where the statistical distribution of all audited sites is listed. This may suggest that those sites were built with greater precautionary measures.
In areas with a groundwater level between >2 to 4 m, 135 sites were audited (32%). For these sites also a relatively close distance to rivers or other waters can be assumed and an exposure of the groundwater to the technical installations underground is very likely.
A comparison of the surveyed distances of "groundwater to surface" with the assigned CR shows that 48% of all sites with a CR 3 lay in the range>2 to 4 m. Because this is the depth where most of the technical installations are installed, the contamination detected is always in contact with the groundwater.
The auditors therefore assigned a relatively high class of risk for environmental hazards and legal recourse within this range.
In areas with a groundwater level >4 to 6 m 70 sites were audited (16%). A hydro-dynamical contact of these sites with surface waters as well as a contact with the underground technical installations is unlikely.
The distribution of CR within this range is the same as in the Table 2.
166 of the audited sites are situated in areas with a groundwater level >6 m. Contact between the technical installations and groundwater can be excluded. In this range the lower CR's are dominant. This is due to the auditor's assessments that in areas with high "groundwater to surface" distance environmental hazards are unlikely.
About 63% of the audited sites classified as CR 2, i. e. hazard to the environment considered unlikely, are situated in areas with a ground-water level >4 m. Within this range the auditors foresaw little risk of environmental pollution and legal recourse.
The CR distribution in the 4 main ranges clearly indicates a relationship between the distance of the "groundwater level to the surface" and the associated class of risk as determined by the audits.

6 The Distribution of Concentrations at the Surveyed Sites

6.1 Substances handled at fuel stations and bulk fuel storage sites

Contaminations at fuel stations and storage sites are often composed of different hydrocarbon products, having similar physical and chemical properties.
Because the vast majority of all the substances, which are handled on such sites, are PHC of a similar quality there will be no differentiation between the various kinds of hydrocarbons within this article.
The ecotoxicological potential of the handled substances can also be viewed in general terms. The handling of halogenated hydrocarbons, which are much more ecotoxic than PHC, is rare at fuel stations and storage sites.

6.2 The extension of PHC contamination in soil

As one would expect the highest degrees of contamination with PHC are close to the locations where the site itself is supplied with PHC and where the customers fill their tanks. Other hot spots for contamination are the areas of the site,where technical installations are underground.
All the results of the audits prove a rapid decline of contamination vertically toward deeper strata of the soil as well as horizontally toward lateral extension. In most cases maximum concentrations decrease on a vertical path after only a few centimetres to neglegible quantities. Laterally the plumes of PHC-contamination in most cases do not extend further than 10 to 20 m. This could be verified through hundreds of examples documented in the audits.

6.3 The extension of contamination shown in an exemplary case

An exemplary case, where locally very high concentrations of PHCwere detected, can be used to demonstrate typical phenomena of PHC-contamination underground. It should include reference to typical sources of error arising from sampling or data collection during the audits.
The small potential for PHC to migrate over greater distances in sediments could always be demonstrated within the actual sites. Surveys beyond the boundaries of the audited sites were therefore not necessary.

6.3.1 A bulk fuel storage site

A storage site for PHC (ca. 40.000 m2) in the federal state of Brandenburg in Germany has been operating since the early sixties in an industrial area of a small city. It was classified in the audit as CR 3. This means that the auditors concluded that a higher risk for legal recourse existed for the landlord of this property.
The (hydro-) geological environment is typical for wide areas of northern Germany. Beneath an up to 4 m thick anthropogenic filling of the ground, medium to fine grained sediments from the ice age compose the strata. The first groundwater level appears 7 m below the surface.
Thirty underground tanks build up the storage site with access to rail, roads and other infrastructure, such as PHC-interceptors. The ground of the site is completely sealed with concrete. The volume turnover in 1992 was ca. 125.000 m3 of PHC.
The aerobic stratum of the underground is only sporadically contaminated. From 17 survey drillings, which were positioned at likely spots of contamination, only 6 showed substantial PHC contents. Five of the 6 drillings showed contamination only within

a range of 20 cm in the bore core. The staff, which did the sampling, selected high-grade contamination from the bore core, although this does not provide much evidence about the average grade of contamination of the investigated site.
Contamination over larger ranges of the bore cores have not been detected, which means that impacts from above the ground have not led to notable contamination of the aerobic zone.
The groundwater and its capillary zone was locally highly contaminated with PHC (max. 223.000 ¦Ìg PHC/l). However, a water gauge downstream of the groundwater flow, which was positioned less than 30 m away from the maximum concentration, showed only 170 ¦Ìg PHC/l. This rapid decline of PHC-concentration after the passage of only a few meters in groundwater bearing clastic sediments is typical and could be proven by hundreds of examples within the audits.
A high level of concrete sealing obviously prevented the aerobic zone from severe contamination.
The massive but local damage of the groundwater probably results from leakages of the underground technical installations.

7 Frequency of Concentration of PHC in Soil Samples after the Evaluation of the Audits for Five Fuel Stations

All surveyed sites have been researched by drilling, sampling and analysing soil as well as groundwater samples. The results of the analyses of soil samples from five fuel stations, whichwere classifiedCR3 in their audits, were counted and put into six ranges of measured concentrations (Table 3).
About 13% of all samples showed concentrations of PHC in soil >3000 mg/kg and 21% of all samples >1000 mg/kg. About 55% of all the samples taken from the five fuel stations showed concentrations of PHC under 100 mg/kg.
This frequency does not represent the average status of contamination on fuel stations because the samples have been taken mostly at hot spots of contamination, such as filling locations. This means that essentially hot spots were surveyed and the average grade of contamination on fuel stations is therefore less.

8 Conclusions

Clastic sediments preventPHCmigrating over large distances.
- The hazards for the environment, which result from contamination with PHC, are highly influenced by the (hydro-) geological embedding of the sites. If groundwater occurs a few meters beneath the underground technical installations the chance of groundwater contamination is small.
Distances of the groundwater to the surface smaller than 4 m are more likely to lead to contamination of groundwater because the retarding effects of the aerobic zone are smaller and contact between the groundwater and the underground technical installations is given in most cases.
- Above ground situation does not play an important role regarding groundwater contamination. Exceptions are major oil spills and the intrusion of larger amounts of PHC into the soil as a result of oil incidents.
- The assignedCRin the audits generally reflects the depth of groundwater. When the groundwater level is far from the surface (>4 m) the auditors in most cases concluded only a small environmental risk was present.
- A defined and precautionary construction of fuel stations and bulk fuel storage sites based on their (hydro-) geological embedding would be possible in order to prevent environmental damage from their operation.
- When a large number of fuel stations or storage sites have to be evaluated, for instance due to change of ownership, a methodical approach similar to the one, which has been designed by the "Treuhandanstalt" allows a realistical assessment of the risk of legal recourse for the investor and last but not least a proper calculation of the selling price for the sites.

Examples of Scientific Criteria that Influence the Capacity of PHC to Migrate Through Soil

The subsoil of the audited sites below the pavement or concrete sealing consists of clastic sediments or an anthropogenic filling with a sediment-like structure or weathered solid rock material. Groundwater bearing, unaltered solid rock was not found on any of the sites.
When PHC migrates through the aerobic zone towards deeper levels of the ground it will sooner or later get in contact with groundwater. Contamination by PHC can happen due to single incidents (oil spills) or leakages over a longer period.
Groundwater with its diluted components represents a single flow system. It could be assumed that PHC migrates with the groundwater flow over longer distances and could endanger clean groundwater resources far away from the centre of contamination.
But as the evaluation of the audits prove, this is impossible due to the physical and chemical properties of PHC and their behaviour in groundwater saturated environments.
PHC are only to about 10 000 to 250 000 ¦Ìg/l soluble in water (Obermann et al., 1990). Because of this negligible solubility, PHC and water build a »two phase flow system« in groundwater saturated sediments. This means that both fluids migrate separately through the porous spaces of the soil. Such a »two phase flow system« behaves much more inertly in sediments than a single flow system (in the aerobic zone the »triple phase system « PHC-water-air behaves even more inertly).
The porous spaces of groundwater bearing sediments contain the described two phases of fluids, which are virtually immiscible.
Only in the centre of contamination, where the saturation of the porous spaces is 100%, can they migrate in parallel through the sediments.
Due to gravity, the force of the groundwater flow and the therefore increasing dispersion, PHC and water will at some distance from the centre of immission no longer form a homogeneous system. The intact layers of PHC around the single grains of the sediments break up because of the decreasing saturation of the sediment.
The migration then stops after a few meters. PHC in this state exist as drops, nests or offsets in the sediment with no or only little contact with each other. If the underground P/T-conditions do not change and new immissions of PHC do not occur this state is irreversible (groundwater migrates quasi on a »detour « around the local PHC accumulations in the sediment). PHC remain in situ within the sediment in the state of residual saturation and will be degraded prospectively by bacterial activities.
In light of the above facts, applying the »Darcy-Law«, which is valid only for single phase flow systems, can lead to unrealistic

assumptions and speculation about the potential danger of PHC migration.
Where both phases are in contact there will be a certain quantity of PHC being diluted in water. A relatively small but stable plume of contamination will be established.
At the edge of such a plume bacterial processes lead to a biochemical equilibrium between the plume and the surrounding clean groundwater resources resulting in no further expansion of the plume (Obermann et al., 1990). This phenomenon is comparable with the behaviour of plumes of other substances that exist beneath municipal garbage dumps (Christensen et al., 1993).
Because of their lower specific gravity PHC will be enriched at the surface of the groundwater (»capillary zone«) if the intruded amount of PHC is large enough to pass the aerobic zone or the groundwater is not to far away from the technical installations underground. This capillary zone with its PHC enriched horizon is divided sharply from strata with lesser contamination.
Only within this enriched horizon (where the saturation is around 100%) is a lateral transfer of PHC possible, but only as long as the two fluid phases co-exist homogenously, as desribed above.
It is mainly due to these phenomena (description however is not complete) that even massive contamination of soil with PHC covers only relatively small areas and generates only local plumes.

LITERATURE

[1] Bonnenberg, H. et al., 1992: Altlastschätzung - ein Arbeitsinstrument zur komplexen Bewertung ostdeutscher Verdachtsstandorte und zur Prognose des Altlasten-Gesamtrisikos. AbfallwirtschaftsJournal, Gütersloh, vol. 4, p. 908-917.
[2] Gesetz zum Schutz vor schädlichen Bodenveränderungen und zur Sanierung von Altlasten - Bundes-Bodenschutzgesetz (BBodSchG), BGBl. I, 17.03.1998.
[3] Obermann, P. et al., 1990: Beurteilung und Behandlung von Mineralölschadensfällen im Hinblick auf den Grundwasserschutz. Herausgeber Umweltbundesamt, Berlin.
[4] Christensen, Th. H., et al., 1993: Verringerung von organischen Schadstoffen in Redoxzonen von Deponiesickerwasserfahnen: In »Altlastensanierung 93«, Hrsg. F. Arendt, G. J. Annokkee, R. Bosman et al., vol. 1, Kluwer Academic Publ., Dordrecht/ Boston/ London, p. 147-158.
[5] Eissmann, L. et al., 1994: Das Quartär Mitteldeutschlands:
Altenburger Naturwissenschaftliche Forschungen, vol. 7, Hrsg. Mauritianum, Naturkundliches Museum, D-04590 Altenburg.
[6] Rat von Sachverständigen für Umweltfragen 1995: Sondergutachten »Altlasten II« Februar 1995; Bundestags-Drucksache 13/380.

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