VEGETATED TREATMENT OF VEHICLE WASH SEDIMENTS: A FIELD DEMONSTRATION

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ABSTRACT

Army training reservations contain vehicle wash facilities where combat and other equipment is washed after field maneuvers. During this process, sediments containing significant concentrations of petroleum hydrocarbons accumulate in concrete sedimentation basins. Conventional treatment methods to decontaminate these sediments include landfill disposal or land application. However, vegetative remediation systems may offer a cost-effective alternative. A phytoremediation design that reduces petroleum hydrocarbons to acceptable levels and is simple to implement and maintain was developed for the Central Vehicle Wash Facility (CVWF), Fort Riley, Kansas. This paper presents a brief outline of site characterization, vegetation treatment system design, and complete results for a two-year study.

Key words: *contaminated sediments, petroleum hydrocarbons, phytoremediation*

INTRODUCTION

Many army-training reservations contain vehicle wash facilities where combat vehicles and other equipment are washed with high-pressure water hoses after field maneuvers. During this process, sediments containing significant concentrations of petroleum hydrocarbons accumulate in sedimentation basins. Significant quantities of these sediments are generated at 12 army installations throughout the United States, two of which are located in the Great Plains/Rocky Mountain region.

Military vehicles at Fort Riley, Kansas, are washed at the Central Vehicle Wash Facility (CVWF). Washwater from the CVWF flows into an impoundment, where particulate matter settles and light petroleum products are removed. Approximately 765 m^3 of water-saturated sediments are removed from the washwater impoundment every six to nine months and spread on the ground surface in 45 to 105 cm thick layers. Laboratory analysis of representative samples of sediments from the impoundment and land application site indicate measurable total petroleum hydrocarbon (TPH) concentration between 482 and 3800 mg/kg. The Kansas Department of Health and Environment (KDHE) generally considers cleanup goals for TPHs in soils as 100 mg/kg, but grants variances depending on future uses of contaminated soils. Conventional treatment methods to manage these sediments include landfill disposal or land application; vegetative remediation systems may offer a cost-effective alternative (Davis et al., 1993; Reilly et al., 1996; Schnoor et al., 1995).

An inexpensive plant treatment system requiring minimal management was designed to treat sediments generated at the Central Vehicle Wash Facility (CVWF), Fort Riley, Kansas. Another vegetation trial was established at the same site to treat sediments from a motor pool waste lagoon. This second trial has been entered in the nationwide Remediation Technologies Development Forum (RTDF) field test for TPH-contaminated soil. This paper presents the details of the vegetation trials and results.

FORT RILEY FIELD TRIAL: 1

Approximately 136 m^3 of sediments from the CVWF were spread on a mowed grassland in July 1997. The sediments were spread approximately 30 cm deep. In September 1997, a vegetative treatment scheme was established with three treatments: (1) an unvegetated control, (2) a grass mixture consisting of tall fescue and western wheatgrass, and (3) a grass-legume mixture consisting of tall fescue with red clover, birdsfoot trefoil, and yellow sweet clover. Each plot was 6 × 6 m in size and all the plots were fertilized with nitrogen and phosphorus. The plots were arranged in a randomized complete block design with four replicates. After seeding the plots in September 1997, management of the trial included three fertilizer applications (23 kg/acre of nitrogen and 11 kg/acre of phosphorus) on all plots; two mechanical clippings of vegetated plots; and four herbicide applications on unvegetated plots.

Sediment samples were collected for preliminary analysis prior to the seeding (July 1997). A composite sample of sediments and the underlying native soil was analyzed for chemical and physical properties. The experimental plots were sampled six times (0, 6, 9, 12, 18, and 24 months after seeding) to determine TPH concentration. During each sampling period, samples were taken from four random places in each plot and a composite was made. This resulted in four composites for each treatment. The composites were air dried, ground, sieved through a 2-mm sieve, and stored in cold room until analysis. A 3-g subsample was taken from each composite and extracted for TPH. Total petroleum hydrocarbon concentrations have been estimated using a procedure that estimates hydrocarbons in the motor oil range by gas chromatography (Schwab et al., 1999).

FORT RILEY FIELD TRIAL: 2 (RTDF TRIAL)

Sediment for the second trial originated from a motor pool waste lagoon that was drained in spring 1999. Sediments were moved to the mowed grassland experiment site in July 1999. The sediments were spread approximately 45 cm deep. In October 1999, a vegetative treatment scheme was established according to the RTDF protocol (http://www.rtdf.org/public/phyto) that includes three treatments: (1) an unvegetated control: weed-free and unfertilized, (2) a standardized grass mixture consisting of tall fescue and legumes, and (3) a site-specific treatment consisting of switch grass. Each plot was 6 × 6 m. All the vegetated plots were fertilized with nitrogen and phosphorus. The plots were arranged in a randomized complete block design with four replicates. After seeding the plots in October

1999, management of the trial included three fertilizer applications (45 kg/acre of nitrogen and 23 kg/acre of phosphorus, each time) on vegetated plots and one herbicide application on unvegetated plots.

Sediment samples were collected for preliminary analysis prior to the seeding. Composite samples of sediments and the underlying native soil were analyzed for chemical and physical properties. The experimental plots were sampled once at planting to determine petroleum hydrocarbon concentrations. Samples were taken from eight random locations in each plot and a composite was made. This resulted in four composites for each treatment. The composites were blended in the field by mixing the random samples in a large mixing bowl. The composites were kept in glass bottles, stored in coolers, transported to the laboratory, and shipped overnight to a contracting commercial laboratory. The commercial laboratory provides analytical services nationwide for the RTDF trials. The hydrocarbon analysis procedures included estimation of TPH (modified EPA method 8015) and PAHs (modified EPA method 8270). Additional analysis of biomarker concentrations and hydrocarbon fractions by the TPH Criteria Working Group method (Vorhees et al., 1999) were also completed to provide a more complete characterization of the petroleum hydrocarbon contaminants.

RESULTS AND DISCUSSION

Fort Riley Field Trial: 1

Figure 1 shows the average TPH concentrations in the soil with a grass mixture during a 24 month period. Initially the TPH concentration was 904 ± 230 mg/kg (mean ± standard deviation), which declined to 432 ± 80 mg/kg in six months. During the first six months of plant establishment, the reduction was about 52%, with continued overall reduction of 73% for the next three months. After 12 months, the TPH had declined to 201 ± 116 mg/kg. This amounts to a 78% reduction during the first year after planting. During the second year of the trial, no further reduction in TPH was observed. The overall reduction in the grass mixture plots was about 76% in 24 months.

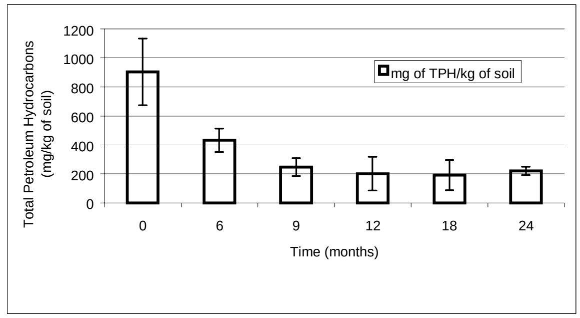

Figure 1. Effect of time on total petroleum-hydrocarbon concentration for grass mixture, Fort Riley Trial: 1.

For the legume treatment, the initial average TPH concentration in the soil was 712 ± 142 (Figure 2). TPH concentration decreased to 463 ± 144 mg/kg in the first six months (35% reduction). During the next three months, the overall reduction was about 60%, and it was only 68% in the next three months (Figure 2). At the end of first growing season, the TPH concentration was 228 ± 101 mg/kg. During the second year, TPH values fluctuated between 151 and 290 mg/kg. The overall reduction in legume-mixture plots was about 59% in 24

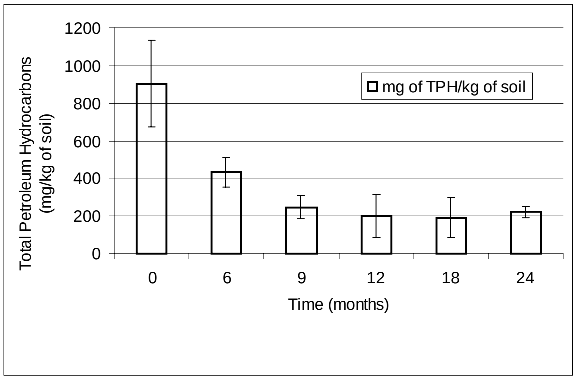

Figure 2. Effect of time on total petroleum-hydrocarbon concentration for legume mixture, Fort Riley Trial: 1.

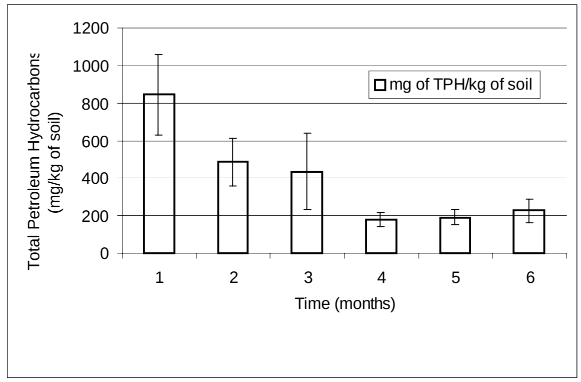

Figure 3. Effect of time on total petroleum-hydrocarbon concentration for unvegetated treatment, Fort Riley Trial: 1.

months. Figure 3 shows the TPH concentration in unvegetated plots over the 24-month period. Initially TPH concentration in the unvegetated plots was 846 ± 214 mg/kg, which decreased to 227 ± 67 mg/kg over the 24-month period (overall reduction of 73%).

TPH concentrations at the beginning of the trial, for all plots, averaged 821 mg/kg. For all plots, the average TPH concentration decreased to 487 mg/kg at six months and 206 mg/kg at 24 months. After 24 months of vegetation treatment, the TPH concentrations declined about 75% from the initial values. Most of the decrease occurred during the first 12 months, and the reduction stabilized over the next 12 months. It is also important to note TPH has been estimated in the motor oil range in this study. If the TPH were estimated for gasoline or diesel range hydrocarbons, the estimated TPH values would likely be lower.

No significant differences have been observed between vegetated and unvegetated treatments by analysis of variance. It is important to note that both the vegetated and unvegetated treatments were fertilized. Therefore, the unvegetated treatment cannot be considered a treatment option that leaves the sediments without management. The TPH concentration at the beginning of this trial was low (821 mg/kg). Considering this low beginning TPH concentration, we have not seen evidence of enhanced dissipation of hydrocarbons with vegetation. Since vegetation helps to hold soil in place and prevent erosion by wind and water, keeping the soil vegetated has value even if there is no significant difference in the rate of biodegradation. This trial will be sampled again after another complete growing season (36 months after planting).

To estimate the concentration of petroleum hydrocarbons in the native soil, a sample of the native soil was taken outside the trial area. The TPH concentration for this sample was 92 mg/kg. Soil samples have also been taken from the native soil at the depth of 30 cm from the ground surface. Estimated TPH for these samples have ranged from 39 mg/kg to 159 mg/kg, with most samples near 100 mg/kg.

Two soil samples from the 24-month sampling were split, and one set was analyzed in our laboratory and the other submitted to the commercial laboratory providing analysis for the second trial. One sample was from a grass-vegetated treatment. The other sample was from the native soil. These samples were analyzed for TPH and PAHs. The TPH estimate of the vegetated treatment was 330 mg/kg (compared against the average grass mixture TPH of 221 ± 30 mg/kg, analyzed in our laboratory). The PAH concentrations for seven probable carcinogenic PAHs were all very low ranging from 0.0041 mg/kg for dibenzo[a, h]anthracene to 0.15 mg/kg for benzo[b]floranthene. The estimated benzo[a]pyrene concentration was 0.0099 mg/kg. These PAHs levels were well below concentrations associated with cancer risk levels stipulated by regulatory agencies. A tier 2 risk-based summary stipulated by Kansas Department of Health and Environment (KDHE) is provided in Table 1. For the commercial laboratory, the TPH concentration of the sample from the native soil was 140 mg/kg (compared against the average native soil TPH of 100 mg/kg, analyzed in our laboratory).

While the values from the commercial laboratory are larger than the values from our laboratory, the differences may be associated with the natural variations associated with sampling and laboratory analysis procedures.

Table 1. Risk-based standards for carcinogenic PAHs by KDHE (source: KDHE, 1999).

	Residential Conditions	
PAH	**Soil Pathway (mg/kg)**	**Soil to Groundwater Protection Pathway (mg/kg)**
Naphthalene	100	39
Acenaphthylene	NA	NA
Acenaphthene	300	190
Fluorene	270	200
Anthracene	13	13
Phenanthrene	NA	NA
Fluoranthene	2700	3800
Pyrene	2000	3000
Benzo[a]anthracene	12	10
Chrysene	1200	1000
Benzo[b]fluoranthene	12	22
Benzo[k]fluoranthene	120	240
Benzo[a]pyrene	1.2	40
Indeno[1,2,3,-c,d]pyrene	12	40
Dibenzo[a,h]anthracene	1.2	3.1
Benzo[g,h,i]perylene	NA	NA

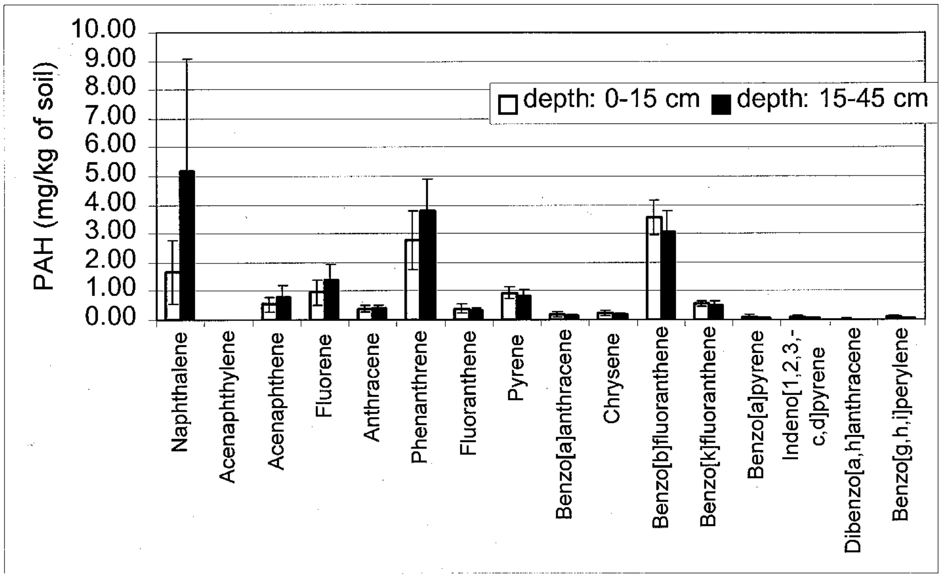

Figure 4. Priority pollutant PAHs in the sediments at planting (fall 1999), Fort Riley Trial: 2.

Based on the fact that the recent TPH values are only about 100 mg/kg above background levels and the PAH concentrations for the seven probable carcinogenic PAHs are all very low, this remediation process appears to be leading to acceptable results.

Fort Riley Field Trial: 2

At the time of planting, the mean TPH concentration (modified EPA method 8015) for all treatments was 14,704 mg/kg for the 0-15 cm depth and 12,792 mg/kg for the 15-45 cm depth. Figure 4 shows the priority pollutant PAHs concentrations in the sediments. The concentration of priority PAHs (modified EPA method 8270) in the sediment for the 0-15 cm was 12.44 ± 3.55 mg/kg, and total concentration of all PAHs was 216.75 ± 81.32 mg/kg. However, the concentration of carcinogenic PAHs in the 0-15 cm depth was only 4.73 ± 0.89 mg/kg.

The concentration of priority PAHs in the sediment for 15-45 cm was 16.79 ± 6 mg/kg, and total concentration of all PAHs was 66.37 ± 95.38 mg/kg. The concentration of carcinogenic PAHs in this layer of sediments was only 3.96 ± 0.98 mg/kg. Naphthalene (a priority PAH) was found in the highest concentration in 15-45 cm sediment layer , and benzo[k]fluoranthene was found in the highest concentration in 0-15 cm layer (Figure 4).

Figure 5 shows the estimated aliphatic petroleum hydrocarbons in the sediments by TPH criteria working group method (CWGM). The total TPH present in 0-15 cm samples by CWGM was 4154 ± 1308 mg/kg, and in 15-45 cm it was 1972 ± 1136 mg/kg. TPH estimated by the CWGM is lower than TPH estimated by method 8015 due to differences in the extraction efficiency of the two methods. Method 8015 uses dicholoromethane as the solvent, and the CWG method uses pentane as the solvent (Vorhees, 2000). The total aliphatic TPH concentration in 0-15 cm samples was 3250 ± 1147 and in 15-45 cm, it was 1328 ± 793 mg/kg. Aliphatic petroleum hydrocarbons having equivalent carbon numbers between 21

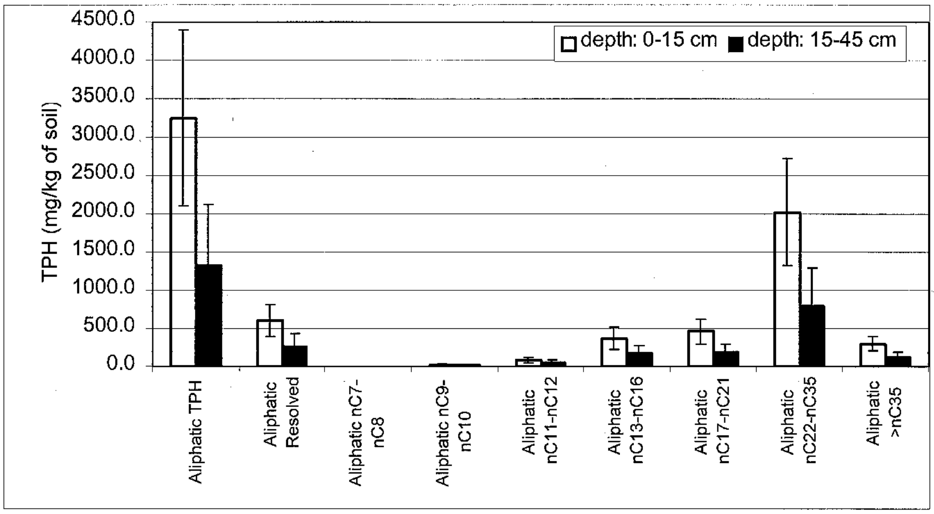

Figure 5. Total aliphatic petroleum-hydrocarbons in the sediments at planting (fall 1999) by TPH criteria working group method, Fort Riley Trial: 2.

and 35 constitute the major aliphatic fraction present in both sediment layers (Figure 5).

The total aromatic petroleum hydrocarbon concentration present in the sediments by TPH CWGM is shown in Figure 6; it is 911 ± 332 mg/kg at 0-15 cm and 640 ± 594 mg/kg at 15-45 cm. Aromatic petroleum hydrocarbons with equivalent carbon numbers between 21 and 35 constitute the major fraction of aromatics presents in both sediment layers (Figure 6).

SUMMARY AND CONCLUSIONS

An inexpensive vegetation treatment system was established to treat sediments from the Central Vehicle Wash Facility (CVWF) at Fort Riley, Kan. Excellent vegetation was established in trial 1, and there was a significant reduction in TPH concentration. The overall reduction was about 75%; however, we did not see significant differences among treatments. We conclude that sufficient reduction of petroleum hydrocarbons can be reached in fertilized soil with or without vegetation for the batch of sediments we used from CVWF in trial 1. This might be due to the low initial hydrocarbon concentrations. Treatment differences with vegetation may be more likely to be evident for sediments with higher initial hydrocarbon levels. The presence of vegetation has several specific advantages, such as controlling soil erosion and leaching as well as improved aesthetic appearance. Vegetation was established in the second trial and the RTDF protocol was implemented. Monitoring of the second trial is ongoing and the trial will be sampled at the end of each growing season (in October) for three years.

ACKNOWLEDGMENTS

This work was partially supported by the U. S. EPA and the U. S. Army funded through Great Plains/Rocky Mountain Hazardous Substance Research Center under assistance agreement R-825549 and R-825550. It has not been submitted to the EPA for peer review and, therefore, may not necessarily reflect the views of the agency and no official endorsement

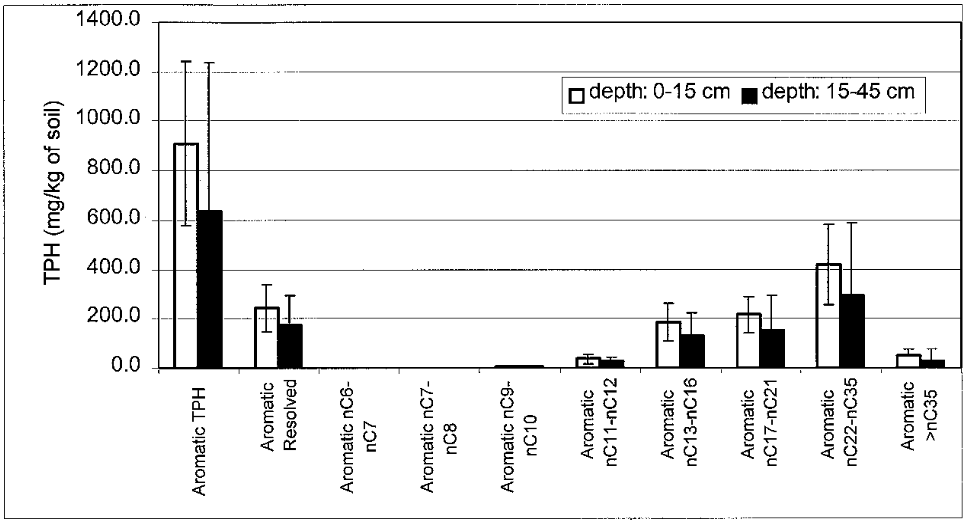

Figure 6. Total aromatic petroleum-hydrocarbons in the sediments at planting (fall 1999) by TPH criteria working group method, Fort Riley Trial: 2.

should be inferred. The Center for Hazardous Substance Research provided partial support. We acknowledge Dr. Xia for use of and assistance with the instrumentation in Throckmorton Plant Sciences Center, Kansas State University.

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