Landfarming on the Alaskan North Slope – Historical Development and Recent Applications

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ABSTRACT

Arctic landfarming of diesel-impacted gravel is being evaluated by BP as a primary North Slope remediation and treatment technology. The method is gaining support with the State agencies and offers an attractive, low-cost alternative to thermal oxidation. Attempts at arctic landfarming in the early 1990s were marginally successful, although multiple (eight-week) seasons were required to reach the stringent cleanup level of 500 mg/kg DRO. Recent applications have demonstrated that thorough tilling of 18 inch gravel lifts on a three-day cycle maintains aerobic conditions and reduces hydrocarbon contaminant levels by 60-70% over a single summer season. Field experiments were performed in 2002 on large (1,000-3,000 cy) plots using various test parameters and vendor applications. Two applications of 20-10-10 fertilizer (0.9 lbs/cy) and utilization of the indigenous soil microbes provided the most effective results. No other enzyme additions or specialized microbial consortiums were required.

INTRODUCTION

Development of the Prudhoe Bay oilfield on the North Slope of Alaska began in 1970, shortly after field discovery in 1968. Production drill sites and processing facilities were constructed on gravel pads that were approximately five feet thick and designed to insulate and preserve the shallow permafrost. During the course of development, fuel spills (predominantly diesel) contaminated minor portions of some pads. BP is currently assessing and removing the now inactive pads in a field-wide remediation and rehabilitation program. Treatment of the contaminated gravel presents a challenge since winter excavation is frequently required and transport distances may exceed 30 miles. When included with the costs of traditional thermal oxidation, gravel remediation costs can approach or exceed $150 per cubic yard (cy).

Various pad remediation methodologies have been investigated over the past 15 years; on-site treatment of the contaminated gravel is preferred. Landfarming and other biotreatment alternatives have been evaluated since at least 1990. Initial in-situ and ex-situ attempts at landfarming experienced variable degrees of success; however, recent ex-situ treatments have demonstrated that the method provides a low-cost, effective alternative to thermal oxidation. Achievement of 500 mg/kg diesel range organics (DRO) cleanup goals and +70% hydrocarbon mass reduction have been demonstrated in a single, eight-week summer season. This report examines the North Slope landfarming methods attempted since 1990 and considers those variables that have potentially contributed to the different levels of success.

REGIONAL SITE CONDITIONS

Harsh, arctic field conditions undoubtedly pose the greatest challenge to landfarming on the North Slope. Temperature measurements and other climate information have been collected for at least 15 years (1) along the Beaufort Sea coastline at Prudhoe Bay and the Barrow (AK) Airport. Mean annual monthly temperature and, growing degree-day units (45˚F base temperature) from 1971-2000 are summarized in Figure 1. These data demonstrate that surface and air temperatures are optimal for plant growth primarily during July and August. Summer warming is reflected in shallow subsurface temperatures by a 2-3 week lag time. Although the temperatures of frequently tilled, shallow (18-24 in) landfarm soil-lifts exceed undisturbed soil subsurface temperatures, the maximum extent of the treatment season is only a 6-8 week period. Soil temperatures in a 2001 landfarming experiment (2) ranged primarily between 35-50˚F, with minimum and maximum spikes of 30 and 62˚F, respectively.

The mean annual precipitation of only 4.16 inches demonstrates that the North Slope is a true desert. This seems contradictory when observing the numerous shallow lakes and saturated tundra. The short thaw season and shallow (12-24 in) depth of relatively impermeable permafrost hinders evaporation and infiltration of the surface water. Most of the precipitation falls during July and August although the amount is insufficient to maintain adequate moisture in the landfarm soil-lifts; water must be added periodically throughout the treatment season.

The pad gravel is mined locally from borrow pits along the major rivers in the Prudhoe Bay field. The material contains 3-10% clay and silt-sized particles, 30-40% sand, and 50-65% gravel (3) and is nutrient-depleted; fertilizer must be added prior to and during treatment (discussed below). The gravel is frequently re-used for pad and road maintenance after treatment.

DESCRIPTION OF INITIAL LANDFARMING ATTEMPTS (1990-1995)

Surfcote Pad

The Surfcote Pad was constructed and occupied during development of the eastern side of the Prudhoe Bay field. Diesel contamination was identified in an approximate 100 x 300 ft area in a former fuel storage area. A pilot test was conducted during 1990 and 1991 by constructing three 25 x 25 ft lined treatment cells on which two feet of contaminated gravel was spread. One control cell (A) was selected, a second (B) was treated with a microbial consortium and fertilizer (amount not specified), and the third (C) only received 200 pounds of ammonium nitrate fertilizer [~4.4 pounds per cubic yard (lbs/cy)]. Soil moisture checks and roto-trimmer tilling were performed approximately twice weekly (frequency of 3-7 days). Water was added to maintain the soil moisture at 3-10% (15-50% of soil capacity) in each plot. The initial DRO concentrations of the blended gravel in the three test plots ranged between 9160 and 9880 mg/kg, and the test was conducted for 41 days (July 26 – September 6, 1990). After that period, the DRO levels had decreased to between 5220 and 5690 mg/kg (44-45% decrease; 74-128 mg/kg/day). A statistical ANOVA demonstrated that no significant difference existed between the treatment types; each plot, including the control cell, decreased significantly and similarly.

The pilot test was continued in 1991. Plot A was again used as a control; Plots B and C received low- and high-dosages of ammonium nitrate fertilizer (22:4:4, NPK). Plot B received a 15:1 C:N ratio (3.0 lb/cy; assumed previous season DRO endpoint, one foot depth penetration) and Plot C received a 7:1 C:N ratio (6.0 lbs/cy). All other variables remained constant; a treatment period of 75 days was utilized (June 22 – September 5). At the end of the 1991 test, DRO levels in the three plots had decreased an additional 51-70%. This resulted in a total DRO decrease for the two years of 77% [Plot A (control); 2159 mg/k final DRO], whereas DRO in Plots B and C decreased by 86 and 87% (1297 and 1250 mg/kg final DRO, respectively). Although no statistically significant difference existed between the two application rates, a statistically significant difference (95% probability) was determined between the fertilized plots (B and C) and the control plot A. The addition of fertilizer increased the biodegradation rate.

Drill Site 1 and 2 Relief Pits

Relief pits are unlined, bermed areas once used to contain the pressure release of oil-water separators in case of an operational upset. In some historic cases, crude oil was discharged to the tundra pit floors; steel tanks are now used to capture such discharges. In-situ landfarming of the affected pit floors was investigated beginning in 1991 through 1995. Various techniques that were applied to the Drill Site 1 and 2 pits included 1) draining, pumping, and ditching in attempts to remove water and aerate the saturated tundra; 2) repeated tilling (8 inch depths); and, 3) fertilizing [0.3 lbs/cy each of 34-0-0 NPK (ammonium nitrate) and 8-32-16 NPK]. Hydrocarbon concentrations in the affected pit floors typically ranged from 500-8000 mg/kg DRO. Although seasonal decreases in the mean DRO levels were occasionally observed, statistical demonstration of a systematic decrease in contamination was not achieved in either pit. This failure was attributed to the saturated soil conditions that persisted despite attempts to de-water, and to high variability in the DRO concentrations in the pit floors.

Service City Pad

The site includes an abandoned gravel pad that was leased by oil field service contractors and served as a former storage, maintenance, and staging area. Diesel contamination was identified (2000-2500 mg/kg DRO) within an approximately 150 ft diameter area at a depth of three feet. Three 50 x 50 ft test plots were prepared in 1992 by installing forced aeration pipes at 3-5 ft depths in vertical trenches (10 ft spacings) and backfilling. Attempts were made to deliver air-flow at 80 standard cubic feet per minute (scfm), although frozen pore water in the deeper trenches restricted air-flow to 40 scfm until thawing occurred late in the summer. This method is considered a bioventing application although information can be gleaned that relates to in-situ landfarming. Each plot received a different treatment – one plot received air only (Plot A), another received air plus fertilizer (B), the third received air, fertilizer, and a bacteria consortium (C). A total of 1.1 lbs/cy of ammonium nitrate fertilizer (liquid form) was applied in 10 treatments to each plot. The test period was 75 days (July 3 – September 15). No statistically significant decrease in DRO concentrations occurred; the initial and final levels in Plots A, B, and C were 1520 vs. 1500, 2520 vs. 2390, and 160 vs. 330 mg/kg, respectively. Failure was attributed to insufficient aeration (frozen ground and saturated soil conditions) and to low in-situ pad temperatures (~38˚F) that were assumed to limit bacterial activity.

DESCRIPTION OF RECENT LANDFARMING APPLICATIONS (2000-2003)

Haliburton Pad

The Haliburton Pad (4) is adjacent to the Prudhoe Bay field. Approximately 7400 cy of diesel-contaminated gravel (1010 mg/kg DRO, mean pad concentration) was identified in the lower half of the six-foot thick pad. Remediation of this large volume of contaminated material by conventional thermal methods was prohibitively expensive and landfarming was approved as a remedial alternative by the Alaska state agencies. An in-situ landfarming method was selected that included treatment amendments by a private vendor [Enzyme Technologies Inc. (ETEC)]. Five treatment cells were constructed within the pad by removing the upper three feet of clean gravel and stockpiling on site. French-drain catchment basins were then constructed within each cell to collect and remove the intra-pad pore water. The mean DRO concentrations for the five cells ranged between 400-1680 mg/kg. Each cell was inoculated on July 24, 2000 with ETEC nutrient enhancers (fertilizer type and quantities unknown), microbial enzymes, and a hydrocarbon-degrading bacterial consortium. Each cell was tilled daily the first week, the rate was reduced to three times per week for the remaining three weeks. A 30-day treatment period was used. At the end of the treatment the mean DRO levels in the five cells ranged between approximately 30-220 mg/kg. The mean pad DRO concentration (average of all treatment cell samples) was 162 mg/kg, reflecting an 84% reduction in hydrocarbon levels.

Service City Pad

A second attempt was made to remediate contamination on the Service City Pad in 2002. Additional assessments revealed contamination over a much larger area than previously identified in the 1992 study. The study was performed by BP in cooperation with the Alaska Department of Environmental Conservation (ADEC) to assess various landfarming treatment methods on a production-sized scale. A total volume of 15,500 cy of contaminated gravel was excavated from an area with contaminant levels that exceeded 2000 mg/kg DRO and that included the former study. Several “hot spots” within this area exceeded 7000 mg/kg DRO. The excavated material was divided proportionally (by truckload) into four treatment plots (1.5 ft lift thickness) in an attempt to “normalize” the starting DRO levels between plots. One plot (1227 cy) was designed as a control cell and received no amendments. Plot A (1314 cy) received two fertilizer applications (20-10-10 NPK; 0.86 lbs/cy total); Plot B (2014 cy) received a proprietary vendor application of nutrients (type and quantity unknown) and a microbial consortium; and, Plot C (11,079 cy) received treatment products provided by ETEC (described above - see Haliburton Pad section). A greater quantity of contaminated gravel was treated with the ETEC products due to the success at the Haliburton Pad. Tilling of the complete lifts was performed with a tractor-led rotary tiller at a frequency of four times per week for the control cell and Plot C, once every three days for Plot A and once every five days for Plot B. The tractor and tiller were decontaminated between tillings of different test plots. A treatment period of 56 days was used. The mean DRO concentration range for each of the four plots was 913-1053 mg/kg at Day 0. Soil moisture was measured daily and maintained at 30-40% for the control cell and Plot A, whereas vendor-specified moisture levels were used in Plots B and C.

The results are summarized in Figures 2 and 3. The decline in DRO concentrations for the four plots ranged between 48-71% (261-506 mg/kg final mean DRO). The highest percentage of DRO decline occurred in Plot A (nutrients only); however, Plot C (ETEC) compared favorably and began with a higher DRO concentration (1046 vs. 913 mg/kg). A non-parametric statistical analysis demonstrated that no significant difference existed between Plot A and C. Figure 2 demonstrates that no appreciable contaminant loss occurred in Plot B and the control plot after Days 14 and 28, respectively. These data suggest that the loss in the control cell and Plot B was due to volatilization and/or leaching since the gravel in the control cell was depleted of nutrients. The similarity in performance between Plots A and C indicate that additions of exotic microbial consortiums and enzymes are unnecessary for Prudhoe Bay remediation. Plate counts of hydrocarbon degrading bacteria were approximately equivalent in Plots A and C ($1.2x10^7$ vs. $1.0x10^7$ colony forming units) at Day 56, demonstrating that indigenous hydrocarbon-degrading bacteria exist at the site and are capable of supporting biodegradation. The test results imply that frequent tilling and nutrient addition is primarily responsible for the contaminant loss at Service City, and that 60% of the loss may be associated with volatilization.

Sea Air Motive Pad

BP conducted an additional landfarming treatment in coordination with the ADEC at the Sea Air Motive pad in 2003 using the same treatment conditions as applied in Plot A (Service City Pad; nutrients only) during the 2002 test. A treatment period of 77 days was used. The pad adjoins the commercial airport (Deadhorse, AK; near Prudhoe Bay) and was used to dispense jet fuel [high gasoline-range organic (GRO) fraction]. Arctic landfarming of the fuel-contaminated gravel was tested; the results are shown in Figure 4. Initial starting concentrations (June 20) of GRO and DRO were 358 and 737 mg/kg, respectively, whereas the final concentrations (September 6) were 101 and 187 mg/kg. Hydrocarbon GRO and DRO reductions were 72 and 75%, respectively. The decline in DRO levels approximates the 71% value observed during the Service City test. Note that the GRO concentration of the freshly stockpiled material (May 23; 1020 mg/kg) declined to the starting level (358 mg/kg) in only 13 days. This reflects the high volatility of the jet fuel. Respiration tests performed during the study reflect a hydrocarbon decay rate of 14.0 mg/kg/day for the study period. Only 1.6 mg/kg/day (11%) was attributed to biodegradation, the remaining 12.4 mg/kg/day was attributed to volatilization and/or leaching.

SUMMARY AND CONCLUSIONS

A review of the various attempts at arctic landfarming over the past 13 years has provided information that will optimize future remediation treatments using this technology. Recent Prudhoe Bay landfarming treatments (since 2000) have been successful; contaminant reductions of approximately 70% of the initial DRO levels have been achieved in a single summer season (60-75 days). Earlier attempts experienced decays of less than 50% in a single season, or in some cases, no reductions at all. Saturated soil conditions and infrequent tilling, i.e. insufficient aeration, appears to be responsible for the poor performance. Recent treatments with multiple test plots have demonstrated that DRO declines of 70-75% over a summer season can be achieved simply by tilling on a 2-3 day schedule, fertilizing (1-1.5 lbs/cy of 20-10-10 NPK; 1000-2000 mg/kg DRO), and maintaining adequate soil moisture (30-40%). The indigenous hydrocarbon-degrading bacteria provide sufficient biodegradation capacity. Exotic nutrients, enzymes, or specialized bacterial consortiums appear to offer no added benefit in the Prudhoe Bay treatments. A hydrocarbon biodegradation decay rate of 1.6 mg/kg/day was recently measured, suggesting that only 11% of the observed decline is attributed to bacteria. The remaining decline is attributed to volatilization and/or leaching.

REFERENCES CITED

1. Western Regional Climate Center, Division of Atmospheric Sciences, Desert Research Institute; Reno, Nevada. http://www.wrcc.dri.edu/cgi-bin/cliGCStG.pl?akbarr.

2. SLR Alaska, "Final Corrective Action Report Service City Pad Prudhoe Bay, Alaska"; prepared for BP Exploration Alaska and submitted to Alaska Department of Environmental Conservation, Anchorage, AK; March 13, 2003.

3. Geosphere, Inc., "Assessing Hydrocarbon Cleanup Levels Appropriate for North Slope Gravel Pads"; prepared for BP Exploration Alaska; draft report, final in preparation.

4. URS Corporation, "Remediation of 17,000 Pounds of Hydrocarbons in One Month"; technical marketing publication; April, 2001.

5. SLR Alaska, "Final Corrective Action Report Sea Air Motive Pad Prudhoe Bay, Alaska"; draft report in preparation for BP Exploration Alaska for submittal to Alaska Department of Environmental Conservation, Anchorage, AK; September, 2003.

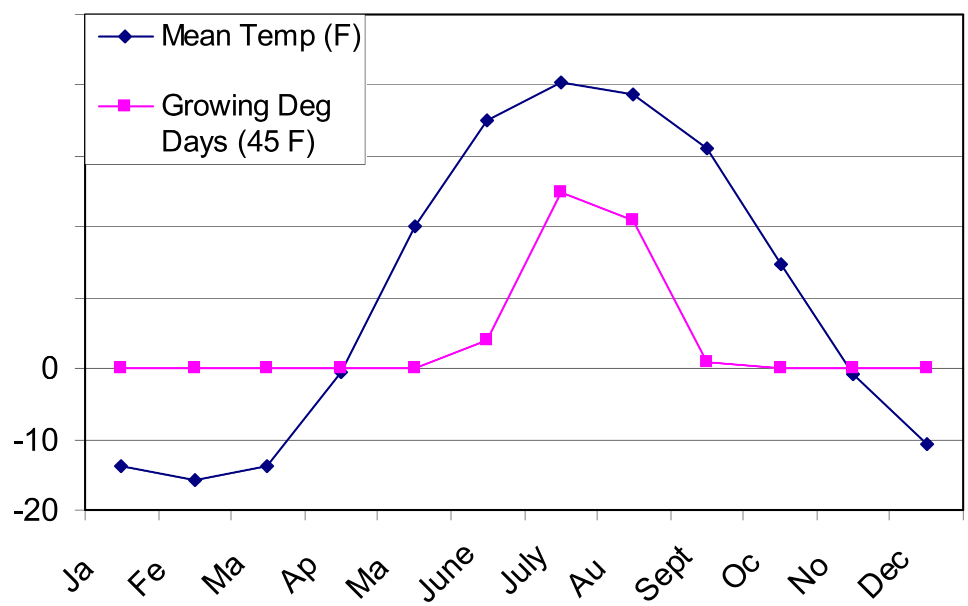

Figure 1. Mean annual monthly temperatures and 45°F growing degree-days at the Barrow Airport (North Slope, AK; approximately 150 miles west of Prudhoe Bay). Mean annual data from 1971-2000.

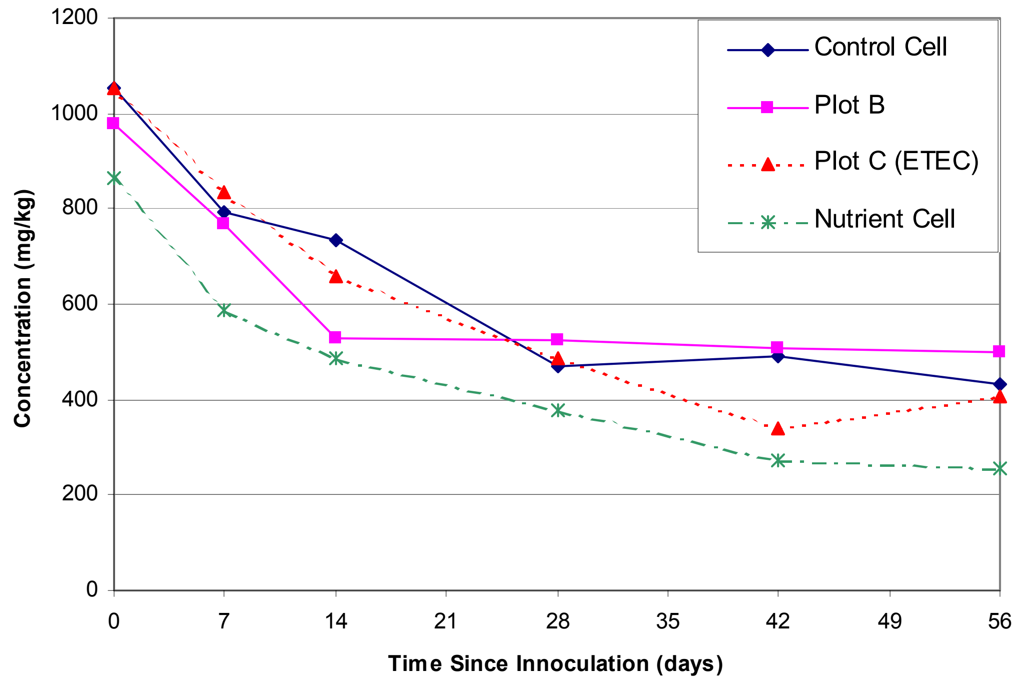

Figure 2. DRO concentrations for individual landfarming treatment plots at Service City pad.

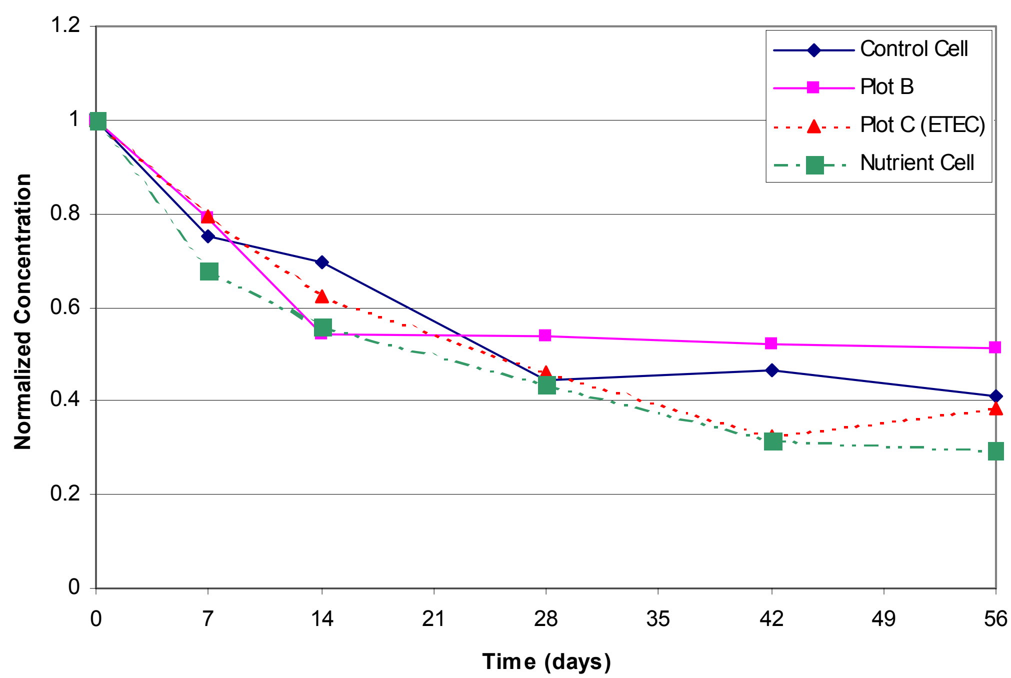

Figure 3. Normalized DRO concentrations for individual landfarming treatment plots at Service City pad.

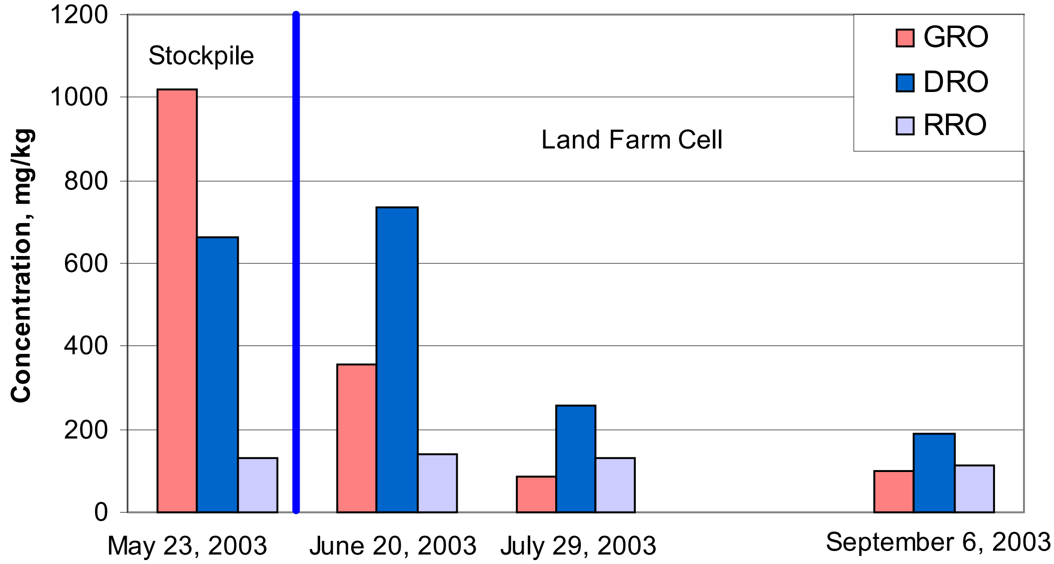

Figure 4. Hydrocarbon GRO, DRO, and RRO concentrations during a landfarming treatment period of 77 days at the Sea Air Motive pad.