

Bioremediation studies at a northern California Superfund site*

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Abstract

Laboratory analysis of land treatment of wood preservative contaminated soils was performed as part of an investigation of remediation alternatives for an EPA Superfund site. Experimental procedure involved 6 different site soils with different supplementary nutrients placed in lined steel boxes, 6' × 12' × 5' deep, and analyzed for, among other things, creosote pentachlorophenol acclimated and total bacteria populations, polynuclear aromatic hydrocarbons (PAHs), and pentachlorophenol (PCP) with both single and multiple loadings. The best overall percentage reduction occurred where there were moderate initial constituent concentrations and the highest level of manure.

Introduction

The J.H. Baxter International Paper Roseburg Superfund site is located in the city of Weed in Northern California. The site is located in the southeastern margin of Shasta Valley, about 10 miles (16 km) west-northwest of the peaks of Mount Shasta and approximately 40 miles (64 km) south of the Oregon/California border. The Baxter site is at an elevation of 3,400 feet (1025 m) above sea level. The site receives most of its average 27 inches (68.5 cm) of precipitation during the winter as rain and snow. Temperatures in the area are generally quite warm in the summer (daytime average of 90°F or 32°C) and cold in the winter (daytime average of 22°F or -5.5°C).

The geology and hydrogeology are fairly complex at the site. The site is underlain by coalescent fans of pyroclastic, mudflow, glacial, and fluvial deposits from the northwestern flank of Mount Shasta and Mount Shastina. The shallow water table, about 5–10 (1.5–3 m) feet below the surface, fluctuates with rainfall and snow melts.

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TABLE 1

Waterborne preservatives used at Weed, California^{a,b} [1]

Preservative	Contents
Minolith	Sodium fluoride (11%), potassium dichromate (12%), dinitrophenol (15%) and sodium arsenate (9%)
Tanalith	Sodium fluoride dinitrophenol (10%) and sodium or potassium dichromate — formulation was mixed with rock salt to provide flame retardance
FCAP	Sodium or potassium fluoride (22%), sodium or potassium dichromate (37%), sodium or potassium arsenate (25%) and dinitrophenol (16%)
Chemonite	Copper hydroxide (31%), arsenic trioxide (22%) ammonia and small amounts of acetic and glycerol
Pyresate	Mixture of zinc chloride, ammonium sulphate, boric acid and sodium dichromate

^aPercentages are based on active compounds, fluoride, chromium trioxide, arsenic as As_2O and the total amount of the organic compound (mass basis).

^bIn some cases dinitrophenol was replaced by sodium pentachlorophenoate.

The site has been an active wood treating plant since 1936. Waterborne and oilborne preservatives, as well as flame retardants, have been used at the site. Waterborne preservatives and flame retardants used are listed in Table 1. Oilborne preservatives have been used extensively at the site. Creosote was used since the start of operations while pentachlorophenol was used only from the 1950's to 1985. Records which were not available before the 1950's indicate that waterborne preservatives had been used since 1950.

The Weed site has several areas where the soil is contaminated with the various wood preservatives. Contaminated areas include two ponds, a spray field, and the areas surrounding a 500,000 gallon (1,900 m³) storage tank, a retort, and the drip pads. Inorganic contaminants are widespread on the site but apparently are largely confined to the soil surface. The organic contamination is less widespread on the site but is often found deep in the soil. Trace levels of both types of contaminants are found in groundwater.

As part of a comprehensive site remediation plan, land treatment of the pentachlorophenol and creosote contaminated soils was considered as a treatment alternative. This study was conducted to determine the feasibility of using land treatment on these soils. The study consisted of three phases, a laboratory phase, a field demonstration study and the final large scale units. The laboratory and field demonstrations have been complete and the final operation units will be built in the near future.

Objective

The overall objective of the laboratory and site demonstration study was to provide information to the regulatory agencies that land treatment bioreme-

diation may be an appropriate and viable method for remediation at the site in Weed, California.

The initial step of site characterization had been completed by the U.S. Environmental Protection Agency (EPA). The specific objective of this study are:

- to determine the rate of breakdown of polycyclic aromatic hydrocarbons (PAHs) in creosote and pentachlorophenol (PCP) using contaminated soil from the site;
- to determine whether the *in situ* bacteria population is sufficient or whether additional bacteria are necessary for adequate degradation;
- to identify any interferences (such as toxic concentrations of metals) which might inhibit microbiological degradation in site soils;
- to undertake field studies to verify that hazardous compounds are not significantly transported during active bioremediation.
- to design and conduct field studies to avoid potential contact of hazardous chemicals with soil and ground water;
- to measure the relative amounts of microbiological breakdown versus transport through the soil to the ground water.

Experimental procedures

The analytical methods used for both laboratory and field demonstration units are given in Table 2. Laboratory studies were done following the treatability-screening procedure developed by the U.S. EPA [2,3]. Soils from various locations on the site were collected and characterized. Rates of biological degradation was determined in the laboratory at $22 \pm 2^\circ\text{C}$ and 1 bar. Moisture content was maintained to 70% water holding capacity and aeration was done at weekly intervals. At 0, 2, 4, 8, and 12 weeks, soil samples (80.0 g) were removed from each test unit and analyzed for creosote/pentachlorophenol acclimated and total bacteria populations, seventeen polynuclear aromatic hydrocarbons (PAHs), pentachlorophenol (PCP), tetrachlorophenol (TeCP), and octachlorodibenzo-*p*-dioxin (OCDD) (Table 3).

The site demonstration was done using 6 steel boxes as shown in Fig. 1. The individual boxes were 6 feet wide by 12 feet long and 5 feet deep, and were lined with a 60-mm synthetic liner. The test boxes were placed on a cement pad. To limit infiltration and to minimize soil loss by wind erosion, a clear plastic canopy was used to cover each open box. The cover was only used during the winter months. Each box was sloped 0.5 to 1.0% and contained a valve located 4 inches (10 cm) from the bottom of the box for collection of water which had moved through the cell. A 1-foot (30 cm) layer of sand was placed directly over each synthetic liner and a (90 cm) 3-foot layer of clean control soil was placed on top of the sand layer in each cell. The clean soil was added in 1-foot lifts and compacted to provide uniform density of the soil in the cells.

TABLE 2

Analytical methods [3]

Process	EPA Method number	Comments
Extraction of soil samples	3540	Use 80 g of soil
Extraction of water samples	3520	Use 1,000 ml of water
Cleanup	3630	Done after methylation of phenols
Analysis of PAHs ^a	8100	For polynuclear aromatic hydrocarbons
Analysis of PCP ^b , TeCP ^c	8040	For chlorinated phenols after methylation using electron capture detector
Analysis of BNAs ^d	8270	Check for all compounds
Analysis of metals	6010	Arsenic, chromium, copper, zinc
Analysis of dioxins	8040	Octachlorodibenzo- <i>p</i> -dioxin
Analysis of TOC ^e		Acid hydrolysis and CO ₂ titration
Analysis of nitrogen		Kjeldahl digestion and colorimetric quantitation
Analysis of phosphorus		Acid digestion and colorimetric quantitation
Analysis of moisture		24-hour 100°C oven drying
Analysis of pH		Soil/water slurry with pH probe

^aPAHs = polycyclic aromatic hydrocarbons.^bPCP = pentachlorophenol.^cTeCP = tetrachlorophenol.^dBNA = base/neutral and acid extractable compounds (includes PAHs).^eTOC = total organic carbon.

TABLE 3

organic chemical parameters used in the Weed box study

Polycyclic aromatic hydrocarbons		Phenols	Dioxin
Naphthalene	Anthracene	Pentachlorophenol	Octachlororodibenzo- <i>p</i> -dioxin
2-Methylnaphthalene	Carbazole	Tetrachlorophenol	
1-Methylnaphthalene	Fluoranthene		
Biphenyl	Pyrene		
Acenaphthylene	1,2-Benzo [a]pyrene		
Acenaphthene	Chrysene		
Dibenzofuran	Benzo [a]purene		
Fluorene	Benzo [ghi]perylene		
Phenanthrene	Total PAHs		

Contaminated soils from two areas, from the tank and from the Roseburg excavated pond, were chosen for the field study because of their high organic contamination levels and because they represented a major portion of the contaminated soil at the site.

Excess water that had drained through the box to the bottom layer of sand was removed at monthly intervals and sent to a treatment plant on site. Ap-

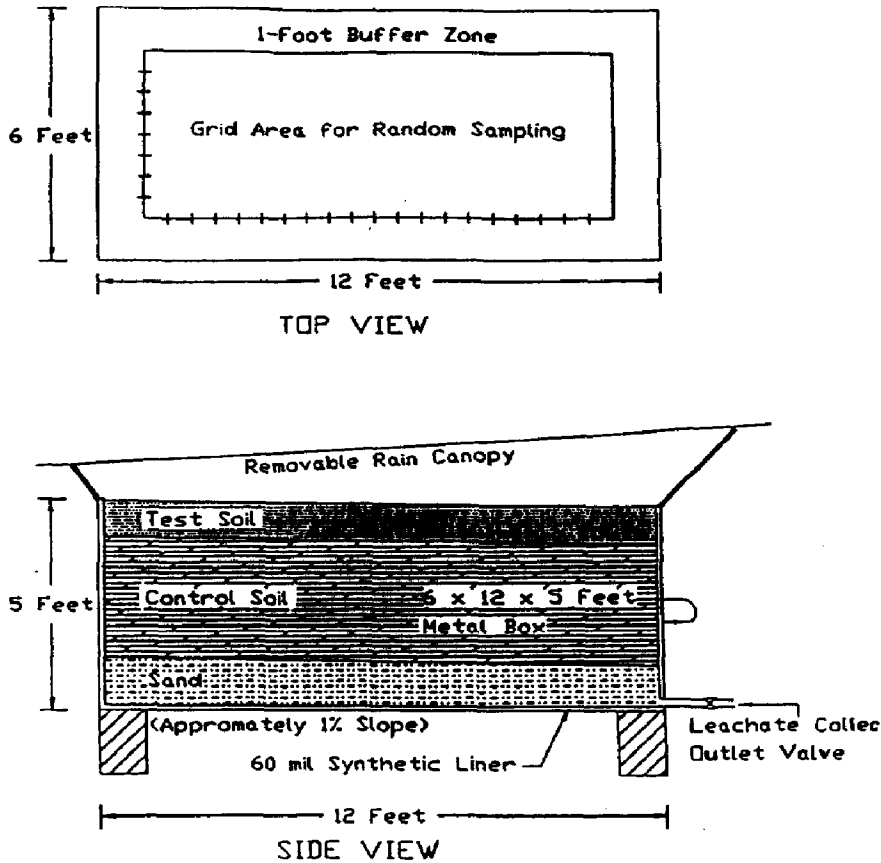


Fig. 1. Design of the steel boxes used for phase II (Site Demonstration) studies at Weed, California.

TABLE 4

Soil parameters for the field studies

Parameter	Value
Soil pH	6.2-7.6
Carbon/nitrogen ratio	30:1 or less
Moisture content	30%-70% of water holding capacity
Aeration frequency	twice weekly
Nitrogen/phosphorus ratio	10:1
Organic carbon levels	2% to 4%

proximately every three days, the test cells were irrigated to maintain 30 to 70% soil moisture. Twice a week, the soils were tilled, weather permitting. The soil parameters that were maintained during the field studies at Weed are given in Table 4.

During fall 1988, spring and summer 1989, each box was sampled at monthly

intervals. Six surface samples were collected at random locations in each box. Six samples were collected at depths of 12 inches (30 cm) and 24 inches (60 cm) using a soil auger. Six samples from each depth were combined into three samples from each box to produce a total of 18 samples/month for all six boxes. The exact collection points were determined using a sampling grid of 6×6 inch (15×15 cm) squares. A random number generator was used to identify 6 grid points within each cell. A one-foot buffer zone where samples were not taken was maintained around each test cell to minimize edge effects. The samples were analyzed for the constituents listed in Table 3.

Results of the laboratory study

Six different site soils were evaluated during the initial laboratory phase of the study. Eventually two soils, tank area soils and excavated pond soils, were used for the site demonstration study. These two soils are the major source of contaminated soils at the site and also had the highest level of contamination. Only the results from the two soils will be discussed in this section.

The overall chemical characterization of the two soils are given in Tables 5 and 6. The levels of nitrogen, phosphorus, and organic carbon in the soils are listed in Table 5. All levels were adequate for biodegradation with the exception of the low organic carbon in the Roseburg excavated pond. The carbon/nitrogen ratios of the tank soils are slightly higher than desirable due to the large amount of woody material in these areas. However, the existing nitrogen levels should be adequate to obtain a good rate of biodegradation. Concentrations of the metals copper, chromium, zinc, and arsenic in the two soils are shown in Table 6. It should be noted that these values are much lower than has been reported in earlier studies. This may be due to the heterogeneous nature of the surface soil. When samples were collected for the site demonstration study using a backhoe (at depth of 30–60 cm the metal levels were over a hundred times higher). Initial concentration of the various organics are also listed in Table 6.

TABLE 5

Soil characterization (ppm)

Type of analysis	Soil source	
	Tank area	Excavated pond
Kjeldahl nitrogen	5,680	765
Organic carbon	241,400	10,720
Phosphorous	1,320	410
Chloride	3.6	8.5
pH	6.44	6.95

TABLE 6

Levels of metals and organic constituents in starting soils (ppm)

Constituent	Soil source	
	Tank area	Excavated pond
Copper	10.4	24.3
Chromium	144.7	269.8
Zinc	23.9	56.2
Arsenic	2267	18.6
Pentachlorophenol	236	ND ^a
Tetrachlorophenol		ND
Total PAHs	14,624	1,095
2-rings	369	ND
3-rings	4,232	601
4-rings	9,631	494
5-rings	392	ND
Octachlorodibenzo- <i>p</i> -dioxin	45.3	ND

^aND = not detected.*Rates of biological degradation**Laboratory phase*

The changes in the concentration of PCP and TeCP over the course of the 84-day laboratory study is shown in Table 7 of biological degradation. As part of this study, a series of dilution with clean soil were prepared and the rates of biological degradation were compared. Two levels of dilution were studied, a 1/2 dilution (tank 1/2) and a 1/4 dilution (tank 1/4). Studies were also done alone or with the addition of trace inorganic constituents (IF) to determine whether the rate of biological degradation was effected by a lack of trace inorganic constituents.

The initial concentrations of the total PAH constituents are given in Table 6. The tank area and excavated pond area had comparable levels of metal constituents (copper, chromium, zinc and arsenic). However, the tank area had much higher levels of organics. The tank area had PAH levels of 14,624 ppm and PCP of 2,267 ppm. While the excavated pond had PAHs levels of 1,095 and non-detectable levels of PCP.

The changes in the concentration of the PAHs and PCP during the course of the 84-day laboratory degradation study is shown in Table 8. The estimated first order rate constants and half-lives (the time needed to degrade a compound to half its initial concentration) for the total PAHs, PCP are given in Table 9.

All classes of PAHs exhibited good breakdown rates in the laboratory. The tank soil had good breakdown rates of both PAHs and PCP with an average PAH half-life of about 70 days and an average PCP half-life of about 103 days.

TABLE 7

Penta- and tetrachlorophenol in weed samples (ppm)^a

Sample ^b	Day 0		Day 14		Day 28		Day 56		Day 84	
	PCP	TeCP	PCP	TeCP	PCP	TeCP	PCP	TeCP	PCP	TeCP
Tank	2,267	236	2,927	273	2,480	223	1,593	220	1,490	200
Tank 1/2	1,153	113	954	87	857	91	897	84	663	100
Tank 1/4	714	61	336	25	345	28	364	26	315	25
Tank IF	2,780	287	2,883	257	2,777	243	1,470	270	1,583	227
Tank 1/2 IF	1,120	113	937	87	879	85	802	77	543	38
Tank 1/4 IF	556	50	400	30	339	28	336	27	324	27
Retort	68	ND	98	ND	47	ND	56	ND	43	ND
Retort 1/2	28	ND	ND	ND	20	ND	ND	ND	13	ND
Retort 1/4	ND ^c	ND	ND	ND	ND	ND	ND	ND	ND	ND
Retort IF	80	ND	82	ND	63	ND	51	ND	47	ND
Retort 1/2 IF	46	ND	30	ND	28	ND	29	ND	15	ND
Retort 1/4 IF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Slump	370	ND	226	ND	160	ND	180	ND	74	ND
Slump IF	554	ND	236	ND	198	ND	173	ND	95	ND
Spray field	ND	ND	ND	ND	NA ^c	NA	NA	NA	NA	NA
Spray field IF	ND	ND	ND	ND	NA	NA	NA	NA	NA	NA
Drip pads	ND	ND	ND	ND	NA	NA	NA	NA	NA	NA
Drip pads IF	ND	ND	ND	ND	NA	NA	NA	NA	NA	NA
Excavated pond	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Excavated pond IF	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

^aEach number represents an average of three replications.^bIn this and the following tables, 1/2 and 1/4 refer to dilutions of the sample soil with control soil; IF refers to added inorganic fertilizer.^cND = not detected.^dNA = not analyzed.

The only exception was the undiluted tank soil with added inorganic fertilizer which had a very long half-life for total PAHs. This may be caused by a high chloride concentration in the soil due to dechlorination of pentachlorophenol and addition of the inorganic trace elements. The rates of breakdown of the PAHs in the excavated pond were comparable to the PAHs in the tank area.

Site demonstration studies

The factors that were studied in the site demonstration study included time, addition of chicken manure, effect of various concentration of constituents and the effects of multiple loading. The exact loading schedule for each box is given below:

TABLE 8

Changes in the PAHs levels (laboratory phase)

Sample	Day 0	Day 14	Day 28	Day 56	Day 84
Tank	14,624	16,311	11,615	10,226	6,611
Tank 1/2	7,824	5,211	4,661	3,058	2,522
Tank 1/4	3,781	2,274	2,250	1,477	1,778
Tank IF	17,116	17,600	16,277	14,993	16,936
Tank 1/2 IF	7,255	4,927	3,822	2,977	1,314
Tank 1/4 IF	3,904	1,927	1,978	1,528	2,272
Excavated pond	1,095	700	579	464	215
Excavated pond IF	1,061	581	455	429	315

^aND = not detected.^bNA = not analyzed.

TABLE 9

Rate constants and half-lives for total PAHs and PCP^a

Sample	Total PAHs		PCP	
	Rate Const. (day ⁻¹)	Half-life (days)	Rate Const. (day ⁻¹)	Half-life (days)
Tank	-0.0100	69	-0.0073	95
Tank 1/2	-0.0133	52	-0.0054	128
Tank 1/4	-0.0095	73	-0.0064	108
Tank IF	-0.0008	866	-0.0089	78
Tank 1/2 IF	-0.0218	33	-0.0207	34
Tank 1/4 IF	-0.0094	74	-0.0049	141
Excavated pond	-0.0162	43	NG ^b	
Excavated pond IF	-0.0124	56	NG ^b	

^aThese values are estimates calculated with a first order rate equation using begin and end concentrations of total PAHs and PCP.^bNG = Pentachlorophenol was not found in this soil.

Box 1 This box was loaded on October 6, 1988 with 12 inches of soil from the tank area and reloaded on June 6, 1989 with 6 inches of soil from the tank area and 12 inches of chicken manure.

Box 2 This box was loaded on October 6, 1988 with 6 inches of soil from the tank area. On June 6, 1989 12 inches of chicken manure was added to the box.

Box 3 This box was loaded on October 6, 1988 with 12 inches of soil from the

TABLE 10

Overall reductions of Weed boxes

Months	Box #	Initial values (ppm)				Final values (ppm)				Reduction percentage (%)		
		PAHs	PCP	OCDD	TeCP	PAHs	PCP	OCDD	TeCP	PAHs	PCP	OCDD
5	# 1 ^a											
	Surface	8,938	641	1.55	68	2,647	149	3.58	13	70	76	
	1 ft.	787	34	0	2.1	1,780	97	0.41	0	-	-	
	2 ft.	2,056	104	0.64	9.5	927	49	0	0	55	53	
	(overall)									(55)	(62)	
4	# 1 ^b											
	Surface	2,960	742	2	49	134	57.5	0	0	95	92	
	1 ft.	3,383	502	2.8	36	3,762	410	2.64	32	-	18	58
	2 ft.	3,058	535	1.55	41	214	18.2	0	0	93	97	
	(overall)									(56)	(73)	(58)
9	# 2											
	Surface	4,793	510	2.75	50.5	0	19.5	1.26	0	100	96	
	1 ft.	1,109	85	0.71	8.5	0	4.59	0	0	100	95	
	2 ft.	1,785	98	0.63	5.2	0	4.44	0	0	100	95	
	(overall)									(100)	(96)	(65)
6	# 3											
	Surface	8,591	723	7.05	72	305	253	4.2	5	96	65	
	1 ft.	441	36	0	0	494	227	5.29	12	100	-	-
	2 ft.	155	8.03	0	2	0	26.6	0.65	0	(91)	-	-
	(overall)										(33)	(0)
9	# 4											
	Surface	13,655	1,075	4.77	130	2,166	455	4.03	29	84	58	
	1 ft.	4,701	233	1.36	22	3,164	325	3.77	29	33	-	
	2 ft.	3,206	140	1.23	15.5	42	4.4	0	0	99	97	
	(overall)									(75)	(46)	(0)
3	# 5 ^c											
	Surface	9,041	554	3.49	64	2,018	107	1.08	7	78	81	
	1 ft.	3,529	158	0.81	16	3,662	154	1.67	11	-	4	
	2 ft.	2,602	98	0.84	7.5	330	16.5	0.17	0	87	83	
	(overall)									(60)	(65)	(43)
	# 5 ^{d,e}											
	Surface	7,398	711	5.6	63	170	53.5	5.88	0	97	92	
	1 ft.	2,704	866	0	22	4,194	859	5.18	67	-	1	
	2 ft.	11	165	0	0	559	76.2	1.25	0	-	94	
	(overall)									(51)	(48)	(0)
4	# 6											
	Surface	3,398	186	4.01	24	372	118	3.65	3	89	37	
	1 ft.	582	150	2.03	0	0	10.5	0.54	0	100	93	
	2 ft.	0	0	0	0	63	20.7	0.68	0	-	-	
	(overall)									(89)	(56)	(19)

^aBioremediation from October 6, 1988-June 6, 1989.

^bBioremediation from June 6, 1989-October 10, 1989.

^cBioremediation from October 6, 1989-December 12, 1989.

^dBioremediation from April 14, 1989-October 18, 1989 - used.

^eUsed the PCP values from July 5, 1989 as the initial values.

TABLE 11

Effect of concentration on reductions in PCP and PAHs

Box #	Initial concentration ^a (ppm)			Reduction (90%)	
	Time (months)	PAHs	PCP	PAHs	PCP
2	9	7,687	693	100	96
3	6	9,187	767	91	33
4	9	21,562	1,451	75	46
6	4	3,908	336	89	56

^aCombined value at all depths (surface, 30 cm and 60 cm results).

TABLE 12

Water analysis from Weed boxes

Box #	April 5, 1989	June 14, 1989	August 2, 1989	October 2, 1989
<i>Pentachlorophenol</i> (ppm)				
1	^a	0.83	0.26	0.024
2	^a	0.039	ND	ND
3	^a	1.34	ND	0.006
4	^a	0.57	ND	ND
5	0.037	0.017	ND	ND
6	ND ^b	0.011	ND	ND
<i>Polycyclic aromatic hydrocarbons</i> (ppm)				
1	^a	0.74	ND	0.35
2	^a	0.28	0.164	1.272
3	^a	0.34	0.033	0.036
4	^a	0.43	0.256	0.076
5	ND	0.17	0.015	0.47
6	ND	0.084	0.031	0.26

^aThese bottles were broken during shipment.^bND = not detected.

excavated pond. On April 14, 1989 it was reloaded with 12 inches of soil from the tank area and 6 inches of chicken manure.

Box 4 This box was loaded on October 6, 1988 with 12 inches of soil from the tank area.

Box 5 This box was loaded on October 6, 1988 with 6 inches of soil from the tank area and reloaded with 24 inches of tank area soil and 6 inches of chicken manure on April 14, 1989.

Box 6 This box was loaded on October 6, 1988 with 12 inches of soil from the excavated pond and reloaded on June 6, 1989 with 12 inches of tank area soil and 6 inches of chicken manure.

TABLE 13

Metal analysis from weed boxes

Box #	Metal (ppm)	
	August 2, 1989	October 2, 1989
	<i>Arsenic</i>	
1	3.08	2.40
2	0.64	0.35
3	0.83	1.73
4	2.24	2.79
5	0.93	1.42
6	0.10	0.026
	<i>Chromium</i>	
1	0.0083	0.140
2	ND	ND
3	0.052	0.053
4	0.003	0.010
5	0.063	0.168
6	ND	ND
	<i>Copper</i>	
1	0.53	1.32
2	0.097	0.040
3	0.30	0.055
4	0.37	0.66
5	0.36	1.31
6	0.065	0.036
	<i>Zinc</i>	
1	20.47	11.72
2	25.15	6.54
3	2.94	14.43
4	10.48	9.69
5	15.80	5.73
6	5.66	2.37

The overall study started on October 6, 1988 and was complete in October 1989.

The percentage reductions of PAHs, PCP, TeCP, and OCDD based on the initial value and final values are given in Table 10. These values are based on a single loading. In the cases where the boxes were reloaded, the reduction after each loading was calculated separately. Boxes 3 and 6, which were initially loaded with excavated pond soil that had contaminant levels below detection levels, were reloaded with tank area soil and percentage reductions were calculated based on the latter loading.

Overall reductions of the constituents varied depending on the remediation time span, the constituent concentrations, and the presence or absence of chicken manure. Boxes 1 and 5 (loaded twice with tank soil) had PAH reduc-

tions of 51% to 60% and PCP reductions of 48% to 73%, while the boxes loaded once with tank soil had PAH reduction of 75% to 100% and PCP reductions of 33% to 96%. Effects of the time span, concentration levels, and presence of manure can best be seen by comparing Boxes 2,3,4, and 6. All four boxes were loaded only once within this group . There were considerable variations in the concentrations of constituents, remediation time, and the presence or absence of manure (Table 11).

The best overall percentage reduction occurred in Box 2 which contained moderate starting constituent concentrations and the highest level of manure. The next highest reduction percentage occurred in Box 6 which had the lowest starting levels of hazardous constituents and half the level of manure contained in Box 2. The lowest reduction occurred in Box 4 which had the highest starting levels of hazardous constituents and no added manure.

Tetrachlorophenol (TeCP) also had fairly rapid breakdown rates (Table 10). The levels of TeCP followed the same trends that were observed for the PAHs and PCP and seemed to depend on the same factors, especially the initial concentration of the constituents and the presence of manure. No TeCP was found at the 2-foot (60 cm) level in any of the boxes at the end of the study.

Some reductions in octachlorodibenzo-*p*-dioxin (OCDD) occurred in boxes 1,2,5, and 6 (Table 10). The levels of OCDD in this study are close to the method detection limits and the variability is fairly large with these results, while interesting, are not to be taken as absolute indication for the biological degradation of OCDD.

In general, the disappearance rates in the boxes were excellent. Bacteria levels were high and good disappearance rates were found at high contaminant levels (e.g. Box 4 with 13,655 ppm PAHs and 1000 ppm PCP). These results confirmed the laboratory results (Phase 1) and expanded the conclusion to longer time periods (1 year) and field conditions.

No drainage water was found in the boxes until heavy rains occurred in March 1989. The drainage water was analyzed for organic constituents for samples taken on April 5, June 14, August 2 and October 2, 1989. The results are given in Table 12.

Parts per billion levels of PCP were found in the box drainage water and generally decreased from April 5 to October 2, 1989. Boxes 1,3,4, and 5 had the highest levels. These boxes were loaded with the highest level of contaminants.

Levels of PAHs in the parts per billion range were also found in the drainage water. The PAH concentrations in drainage water from some boxes increased and others decreased with no apparent consistent pattern. The distribution of the various PAHs (data not shown) indicated that the products moved in the oil phase. When PAHs move in the water phase, the major constituents moving are the lower molecular weight compounds (e.g. bicyclics and tricyclics). In contrast, movement of PAHs in the oil phase favors the movement of the higher molecular weight PAHs. The metal concentrations in the drainage water are

given in Table 13. The major metal constituents found in the drainage water were arsenic and zinc which are more water soluble than the other metals under these conditions (Table 13).

References

- 1 B.A. Richardson, Wood Preserving, The Construction Press, Lancaster, 1978.
- 2 U.S. EPA, Permit Guidance Manual on Hazardous Waste Land Treatment Demonstrations, Final Draft, EPA-530/SW86-032, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, DC, 1986.
- 3 U.S. EPA, Test Methods for Evaluating Solid Waste, 1B. SW-846, 3rd edn., U.S. Environmental Protection Agency, Washington, DC, 1986.