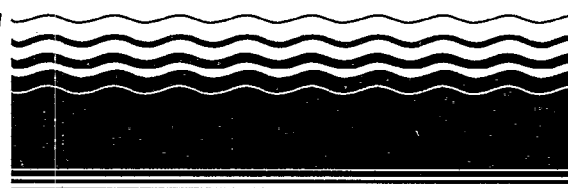




SITE SUPERFUND INNOVATIVE TECHNOLOGY EVALUATION



Technology Demonstration Summary

Resources Conservation Company's Basic Extractive Sludge Treatment (B.E.S.T.[®]); Grand Calumet River, Gary, Indiana

An evaluation of Resources Conservation Company's (RCC) Basic Extractive Sludge Treatment (B.E.S.T.[®])* pilot plant was conducted between July 1 and July 22, 1992, during a demonstration by the U.S. Environmental Protection Agency (EPA), under the Superfund Innovative Technology Evaluation (SITE) Program. The demonstration evaluation was conducted in Gary, IN; the material treated was contaminated river bottom sediments collected from two locations within the Grand Calumet River (GCR). The organic contaminants of concern were PCBs and PAHs. Figure 1 shows the general locations of the demonstration test area, test sediment collection points in the GCR, and major regional features.

This demonstration was part of a cooperative effort. In addition to the EPA SITE Program, other agencies involved included EPA's Great Lakes National Program Office (GLNPO); the U.S. Army Corps of Engineers (COE), Chicago District; and EPA Region V. The GLNPO Assessment and Remediation of Contaminated Sediments Program through the COE, in cooperation with EPA Re-

gion V, arranged for the developer's services and the location where the demonstration was conducted.

GLNPO leads efforts to carry out the provisions of Section 118 of the Clean Water Act (CWA). Under Section 118(c)(3) of the CWA, GLNPO is responsible for undertaking a 5-yr study and demonstration program of methods for the assessment and remediation of contaminated sediments. One of the areas of concern for priority consideration is the GCR. The COE (Chicago District) has authorization (Rivers and Harbors Act of 1910) to maintain harbor channels by periodic dredging. This includes the federal channel at Indiana Harbor downstream of the GCR. However, EPA has designated the bottom sediments at various locations as moderately polluted, heavily polluted or toxic. As a result, materials to be dredged from the Indiana Harbor and Canal are not suitable for open-water disposal in Lake Michigan. At the present time, an environmentally acceptable disposal facility for dredged materials from Indiana Harbor does not exist. Consequently, dredging to maintain adequate navigation depths has

* Mention of trade names and commercial products does not constitute endorsement or recommendation for use.



not been conducted at this harbor since 1972.

The B.E.S.T.® Process is a patented solvent extraction system that uses triethylamine at different temperatures to separate organic contaminants from sludges, soils, and sediments. The organics are concentrated in an oil phase, thereby reducing the volume of wastes that require further treatment. Multiple extractions are conducted at predetermined process conditions and are followed by solvent recovery, oil polishing, solids drying, and water stripping.

The use of triethylamine as the extracting agent distinguishes B.E.S.T.® from other solvent extraction and soil washing technologies. Triethylamine has a property known as inverse miscibility. At temperatures below 60°F, triethylamine is miscible with water; above 60°F, triethylamine is only slightly miscible with water. Therefore, at temperatures below 60°F, solids can be dewatered and organic contaminants can be extracted simultaneously. This process is referred to as a cold extraction. Following cold extractions, the extraction temperature is raised above 60°F, and any remaining organic contaminants are removed. These warm and hot extractions are usually conducted at temperatures ranging between 100°F and 170°F. The organic contaminants initially present in the sludge or soil are concentrated in the oil fraction; additional treatment (e.g., incineration) is required to destroy or immobilize these contaminants.

This Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, Ohio to announce key findings of a SITE Program demonstration, which is fully documented in two separate reports (see ordering information at back).

Introduction

The SITE Program was established in 1986 to promote the development and use of innovative technologies to remediate Superfund sites. One component of the SITE Program is the Demonstration Program, through which EPA evaluates field or pilot-scale technologies that can be scaled up for commercial use. The main objective of the demonstration is to develop performance, engineering, and cost information for these technologies.

This Technology Demonstration Summary highlights the results of an evaluation of the effectiveness of the B.E.S.T.® Process to remove PAHs, PCBs, and oil and grease (O&G) from bottom sediments collected from the GCR in Gary, IN.

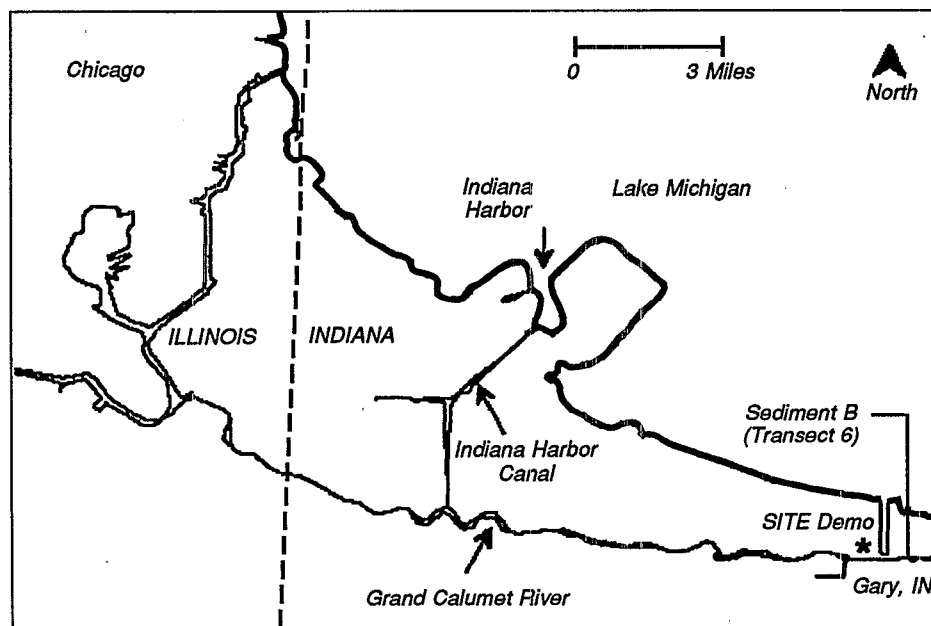


Figure 1. Regional location map.

Sample locations were chosen to obtain two different sediment types, Sediment A and Sediment B. Sediment A contained high concentrations of metals and low concentrations of organic compounds, relative to Sediment B. Sediment B, collected upstream from Sediment A, contained high concentrations of organic contaminants such as PAHs, PCBs and O&G.

Prior to the demonstration testing, both sediment types were prescreened to separate oversize materials and were thoroughly homogenized (mixed). Separate bench-scale treatability tests were then conducted on each of the sediment types. These tests were performed by RCC to determine initial operating conditions, such as the number of extraction cycles, to be used in the demonstration. A flowchart of the experimental design used to guide the B.E.S.T.® evaluation is shown as Figure 2.

The demonstration consisted of two separate tests, one for each sediment type. Each test consisted of two phases. Phase I involved determination of the optimum process variables from the results of three runs, and Phase II consisted of two additional runs at the determined optimum conditions. Samples of the untreated sediments, product solids, product water, and product oil were collected during each of the five runs (Phases I and II). These samples were analyzed for total PAHs, PCBs, and O&G. Product solids, product water, and product oil were also analyzed for residual triethylamine solvent.

Results of the demonstration showed that the process met (or exceeded) the vendor's claims for organic contaminant removal efficiency of $\geq 96\%$ for treating both of the test sediments. The analytical results for Sediment A indicated that the process removed greater than 98% of the O&G, greater than 99% of the PCBs, and 96% of the PAHs. The residual solvent in

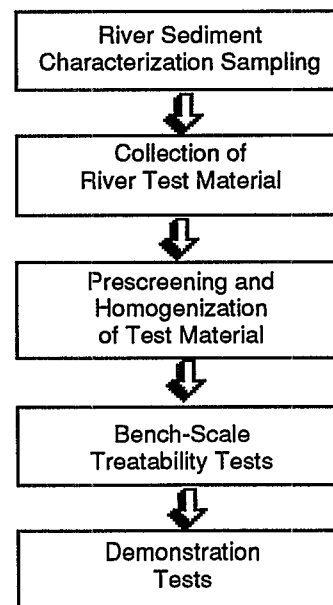


Figure 2. Experimental design flow diagram.

Process Description

- A high vapor pressure (therefore the solvent can be easily recovered from the extract of oil, water, and solvent through simple steam stripping)
- Formation of a low-boiling azeotrope with water (therefore the solvent can be recovered from the extract to very low residual levels, typically less than 100 ppm)

- A heat of vaporization one-seventh that of water (therefore, solvent can be recovered from the treated solids by simple heat with a very low energy input)
- Alkalinity ($\text{pH}=10$) (therefore some heavy metals can be converted to metal hydroxides, which can precipitate and exit the process with the treated solids).

The cold extractions are repeated as additional feed is added to the Premix Tank to accumulate enough solids to perform subsequent extraction cycles. Solids with high moisture contents may require more than one cold extraction. During this

Once a sufficient volume of moisture-free solids is accumulated, it is transferred to the steam-jacketed Extractor/Dryer. Warm triethylamine is then added to the solids. This mixture is heated, agitated, settled and decanted. The warm and hot extractions separate the organics not removed during the initial cold extractions. Three products are derived from the total process: product solids, product water, and concentrated oil containing the organic contaminants.

The pilot plant used for this demonstration is a self-contained mobile unit that allows onsite testing to be performed at a pilot scale. It consists of two portable skids that are mounted on a low boy trailer (8 ft x 45 ft) on which the unit is transported. The process skid (20 ft x 8 ft) has two levels and contains the majority of the B.E.S.T.[®] process equipment including the Premix Tank, the Extractor/Dryer, the Solvent Evaporator, the Centrifuge, storage tanks, pumps, and heat exchangers. The second smaller utility skid (10 ft x 8 ft) contains several utility systems to support the operation of the process skid, including a refrigeration unit used to cool the solvent. Power requirements for the pilot plant are 480 volts, three-phase power at 225 amps, which is accessed from a main

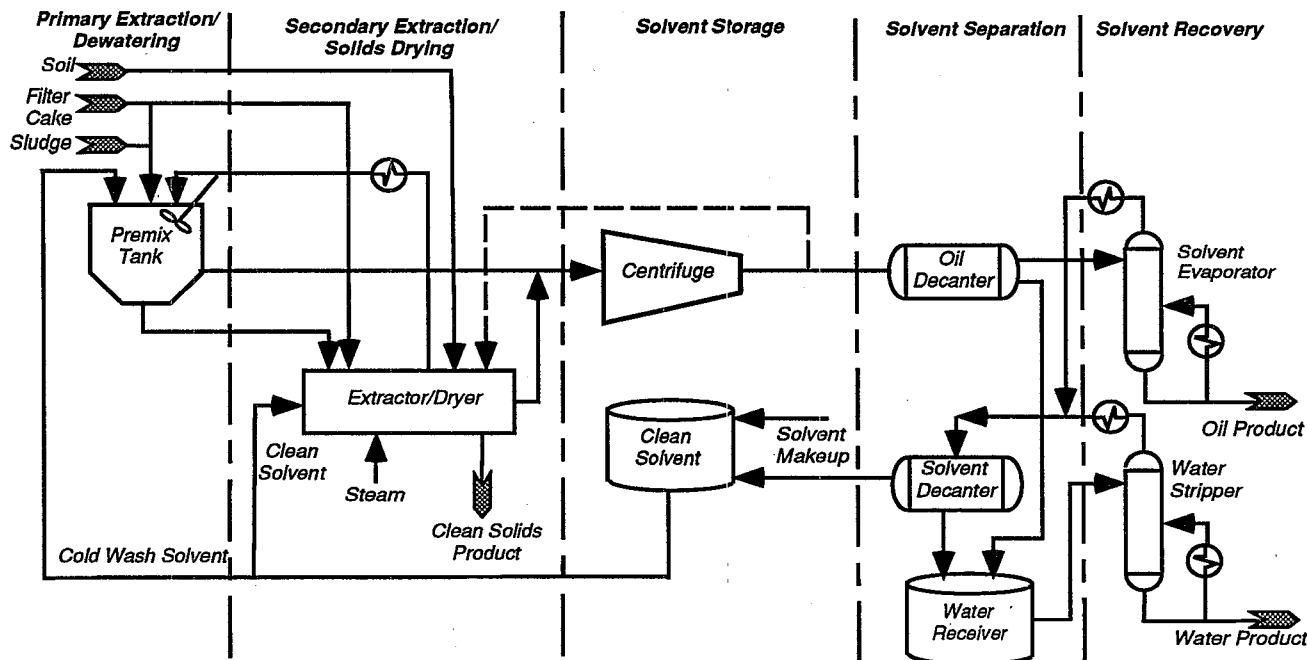


Figure 3. Generalized diagram of the RCC B.E.S.T.[®] solvent extraction process.

power source (i.e., electrical drop) by an electrical distribution panel supplied by RCC. A support trailer accompanies the pilot plant, transporting ancillary equipment and providing a storage and working facility during testing.

Test Program

The primary objective of this SITE demonstration was to evaluate the effectiveness of the B.E.S.T.[®] solvent extraction technology on two test sediments having different contaminants or contrasting concentration levels of the same contaminants. Therefore, the sediments treated were collected at two different transect locations along the east branch of the GCR (see Figure 1). Sediments collected and homogenized from Transect 28 were designated Sediment A, and sediments collected and homogenized from Transect 6 were designated Sediment B. The transect locations were located approximately 2 miles apart. The Sediment A (Transect 28) location was located slightly downstream of an oil-skimmed settling lagoon, which receives wastewater from primary bar plate mills and basic oxygen process (BOP) shops. Sediment B (Transect 6) was located slightly downstream from the discharge of a coke plant. Sediment A consisted of high levels of metals and low levels of organic contaminants relative to Sediment B. Sediment B was composed of high levels of organic contaminants and lower levels of metals.

Prior to the demonstration, each of the two sediment types was prescreened, thoroughly homogenized, and subjected to bench-scale treatability testing. These tests, which were conducted by RCC, provided initial operating conditions. Critical measurements were identified with the aid of sediment characterization analyses. The critical parameters selected for the demonstration tests were:

- PAHs and PCBs in all solid and liquid process streams
- O&G in the feed material, treated solids, and water phase (O&G was identified as critical because oil is a process residual)
- Triethylamine in the treated solids, water phase, and oil phase
- Moisture in the feed material and treated solids
- Toxicity Characteristic Leachate Procedure (TCLP) metals in the feed material and treated solids
- Masses of feeds (including steam and caustic)
- Masses of treated residuals (solids, oil, water, and recovered solvent)

After the initial conditions and critical measurements were determined, the ac-

tual demonstration testing was initiated. A pilot-scale unit was utilized to conduct the testing, and was batch-loaded on average with approximately 170lbs of wet sediment/batch (test run). Two demonstration tests were conducted, one for each sediment type. Each demonstration test consisted of two phases. Phase I involved the determination of optimum process variables for each test sediment. These variables included number of extraction cycles, mixing times, and extraction temperature. Three sets of conditions, determined by RCC, were tested. Phase II consisted of two additional runs at optimum conditions determined in Phase I. This resulted in a

total of three runs at optimum conditions for each sediment type. Tables 1 and 2 present the actual sequence of extraction cycles conducted during the demonstration for Sediments A and B, respectively.

Samples were collected and analyzed for each process stream specified in Table 3. PAHs, PCBs, and O&G were critical analyses for all media except vent gas. These contaminants were known to be in both sediment types and were the primary constituents targeted for removal using the B.E.S.T.[®] Process. Triethylamine was targeted for analysis in the product streams and vent gas emissions because of its

Table 1. Extraction Sequence Used for Sediment A

Extraction Temperature (°F)					
Phase I ^a			Phase II ^a		
Extraction Cycle	Run 1	Run 2	Run 3	Run 4	Run 5
1	cold (62)	cold (50)	cold (53)	cold (48)	cold (52)
2	warm (106)	cold (40)	cold (45)	cold (42)	cold (46)
3	warm (95)	cold (38)	warm (100)	warm (110)	warm (97)
4	warm (95)	warm (98)	hot (155)	hot (155)	hot (152)
5	warm (103)	warm (125)	hot (166)	hot (163)	hot (167)
6	hot (170)	hot (160)	hot (166)	hot (164)	hot (160)
7	—	hot (160)	hot (166)	hot (164)	hot (160)

^a Shaded columns indicate the three optimum runs.

Table 2. Extraction Sequence Used for Sediment B^a

Extraction Temperature (°F)					
Phase I ^a			Phase II ^a		
Extraction Cycle	Run 1	Run 2	Run 3	Run 4	Run 5
1A 1	cold (49)	cold (28)	cold (32)	cold (28)	cold (51)
1A 2	cold (47)	cold (42)	cold (40)	cold (48)	cold (41)
1A 3	(NC) ^c	cold (38)	cold (40)	cold (39)	cold (39)
1B 1	cold (41)	cold (39)	cold (29)	cold (51)	cold (39)
1B 2	cold (53)	cold (47)	cold (38)	cold (53)	cold (45)
1B 3	cold (52)	cold (36)	cold (46)	cold (46)	cold (44)
2	hot (145)	hot (152)	hot (151)	hot (147)	hot (146)
3	hot (152)	hot (157)	hot (150)	hot (156)	hot (160)
4	hot (161)	hot (150)	hot (152)	hot (170)	hot (153)
5	hot (148)	hot (152)	hot (151)	hot (155)	hot (154)
6	hot (157)	hot (151)	hot (146)	hot (158)	hot (152)
7	hot (143)		hot (150)		

^a Because of the high moisture content of Sediment B, both sediment and solvent were fed to the Premix Tank. The portions of each were limited so that the temperature rise of the solvent/water phase was at an acceptable limit.

^b Shaded columns indicate the three optimum runs.
^c NC = Not conducted

Table 3. Summary of Analyses Conducted for the RCC B.E.S.T.® SITE Demonstration

Parameter	Untreated Sediment (Raw Feed)	Treated Sediment (Product Solids)	Water Phase (Product Water)	Decant Water (from Raw Feed)	Oil Phase (Product Oil)	Intermediate Solvent/Oil Mixture	Solvent Feed and Recycled Solvent	Vent Gas
Critical								
PAHs ^a	▲	▲	▲	▲	▲	▲	▲	
PCBs	▲	▲	▲	▲	▲	▲	▲	
Oil and Grease	▲	▲	▲	▲				
Moisture ^b	▲	▲			▲			
Triethylamine		▲	▲		▲			▲
TCLP Metals ^c	▲	▲						
Non-Critical								
Total Suspended Solids			▲	▲			▲	
Proximate/Ultimate	▲	▲			▲			
Total Metals ^d	▲	▲	▲	▲				
Total Recoverable Petroleum Hydrocarbons	▲	▲	▲	▲				
Volatile Solids	▲	▲	▲					
Total Cyanide	▲	▲	▲					
Reactive Cyanide	▲	▲						
Reactive Sulfide	▲	▲						
Particle Size	▲	▲						
Total Phosphorus	▲	▲	▲					
pH	▲	▲	▲					
Total Dissolved Solids			▲	▲				
Total Organic Carbon/Total Inorganic Carbon			▲					
Biochemical Oxygen Demand			▲					
Conductivity			▲					
Special Studies								
Biodegradation		▲						

^a Specific PAH compounds analyzed for are presented in table 4.

^b Moisture was critical for all samples except for the oil phase.

^c TCLP metals include As, Ba, Cd, Cr, Pb, Hg, Se, and Ag.

^d Total metals include Sb, As, Ba, Be, Cd, Cr, Cu, Mn, Hg, Ni, Se, Ti, Va, and Zn.

potential as a process residual. Moisture content and TCLP were considered critical because of the original characteristics of the sediments (high moisture and metals contents).

Six main process streams were sampled and analyzed for each of the two tests. These process streams included untreated sediments (raw feed), product solids, product water, product oil or oil/solvent mix, recycled solvent, and vent emissions. Decant water collected from buckets holding the feed material from one of the Sediment B batches was also sampled. Each lot of product triethylamine was sampled prior to use.

Results

The following data summary is derived from this SITE demonstration:

- Contaminant reductions of 96% or greater for total PAHs and greater than 99% for total PCBs were achieved from treatment of bottom sediments collected from Transect 28 (Sediment A) of the GCR. Contaminant reductions of greater than 99% for total PAHs and greater than 99% for total PCBs were achieved from treatment of bottom sediments collected from Transect 6 (Sediment B) of the GCR. Table 4 provides the

percent removals for individual PAH compounds from test sediments, as determined from averaging the three optimum runs. Table 5 presents the PCB removal efficiencies from test sediments for each test run and as total and optimum run averages.

- O&G removal efficiencies in excess of 98% were achieved in the treated solids generated from both sediment types, as shown in Table 6.
- Mass balances calculated for all materials entering and exiting the process indicated that very good mass balance closures were achieved from

Table 4. PAH Removal Efficiencies

PAH Analyte	Sediment A			Sediment B		
	Feed ^a	Treated Solids ^a	% Removal ^b	Feed ^a	Treated Solids ^a	% Removal ^b
Acenaphthene	68	1.3	98.1	12800	42	99.7
Acenaphthylene	<16	<0.8	—	210	6.6	96.9
Anthracene	22	1.3	94.1	2370	16	99.3
Benzo(a)anthracene	25	0.52	97.9	1050	4.7	99.6
Benzo(a)pyrene	24	0.34	98.6	810	4.6	99.4
Benzo(b)fluoranthene	23	0.36	98.4	857	4.1	99.5
Benzo(k)fluoranthene	17	0.22	98.7	533	3.6	99.3
Benzo(ghi)perylene	15	0.20	98.6	457	2.3	99.5
Chrysene	25	0.52	97.9	937	4.7	99.5
Dibenz(a,h)anthracene	<18	<0.76	—	140	<2.9	>97.9
Fluoranthene	76	1.4	98.2	4280	16	99.6
Fluorene	51	1.9	96.3	7290	35	99.5
Indeno(1,2,3-cd)pyrene	15	0.18	98.8	547	2.2	99.6
2-Methylnaphthalene	25	3.7	85.2	6410	83	98.7
Naphthalene	<18	5.1	—	18700	230	98.8
Phenanthrene	92	3.6	96.1	10800	41	99.6
Pyrene	67	1.0	98.5	2810	12	99.6
Total PAHs	548	22	96.0	70920	510	99.3

^a Concentrations reported in mg/kg (dry weight basis) and are the average of the three optimum runs for each sediment. (Sediment A = Runs 3, 4, and 5; Sediment B = Runs 2, 4, and 5.)

^b Percent Removals = $\frac{\text{Feed Concentration} - \text{Treated Solids Concentration}}{\text{Feed Concentration}} \times 100$

treatment of both test sediments. Closures of 99.3% and 99.6% were obtained for Sediments A and B, respectively.

The products generated using the B.E.S.T.[®] Process were consistent with RCC's claims with regard to residual triethylamine concentrations. Average triethylamine concentrations of 103 mg/kg, less than 1 mg/L, and 733 mg/kg for solid, water, and oil product, respectively, were generated during the treatment of Sediment B (Transect 6). Solid and water products generated from the treatment of Sediment A achieved average residual triethylamine concentrations of 45 mg/kg and less than 2 mg/L, respectively. Product oil was not generated from treatment of Sediment A because Sediment A originally contained very little oil (less than 1%). A summary of RCC's claims, and actual triethylamine concentrations in the treated solids, product water, and product oil are presented in Table 7.

Costs

Operating and equipment capital cost estimates were developed for the proposed full-scale B.E.S.T.[®] system. The cost estimates were based on information provided by the vendor and on several assumptions. These assumptions were based on the experiences of this demonstration and a previous full-scale test conducted at a site in Georgia. Certain cost factors which were not included in the treatment cost estimate were assumed to be the responsibility of the site owner/operator. Costs associated with system mobilization, site preparation, startup, and

Table 5. PCB Removal Efficiencies

Parameter	R1	R2	Test Runs			Avg ^c	Standard Deviation ^c
			R3	R4 ^a	R5 ^b		
Sediment A							
Total PCBs - Feed (mg/kg - dry weight)	7.33	6.41	8.01	11.8	16.4	10.0/12.1	4.1/4.2
Total PCBs - Treated Solids (mg/kg - dry weight)	<0.07	0.20	0.05	0.04	0.04	0.08/0.04	0.07/0.006
Percent Removal (%)	>99	96.9	99.4	99.7	99.8	99.2/99.7	—
Sediment B							
Total PCBs - Feed (mg/kg - dry weight)	364	316	495	462	497	427/425	82/96
Total PCBs - Treated Solids (mg/kg - dry weight)	1.5	2.1	1.2	1.8	1.4	1.6/1.8	0.35/0.35
Percent Removal (%)	99.6	99.3	99.8	99.6	99.7	99.6/99.6	—

^a Concentrations reported for Run 4 are the average of three field replicate measurements.

^b Concentrations reported for Run 5 are the average of samples analyzed in triplicate.

^c Two values are given; the first pertains to all five runs and the second pertains to the three optimum runs (Sediment A=Runs 3, 4, and 5 and Sediment B=Runs 2, 4, and 5).

Table 6. Oil and Grease Removal Efficiencies

Parameter	Test Runs					Avg ^c	Standard Deviation ^c
	R1	R2	R3	R4 ^a	R5 ^b		
Sediment A							
Total Oil & Grease - Feed (mg/kg - dry weight)	9400	7800	7400	6600	6700	7580/6900	1030/436
Total Oil & Grease - Treated Solids (mg/kg - dry weight)	195	169	203	66	65	140/111	69/79
Percent Removal (%)	97.9	97.8	97.3	99.0	99.0	98.2/98.4	—
Sediment B							
Total Oil & Grease - Feed(mg/kg - dry weight)	66,400	116,000	67,300	167,000	99,100	103,000/ 127,000	41,600 35,300
Total Oil & Grease - Treated Solids (mg/kg - dry weight)	1800	1330	1490	1230	1810	1530/1460	266/310
Percent Removal (%)	97.3	98.9	97.8	99.3	98.2	98.5/98.9	—

^a Concentrations reported for Run 4 are the average of three field replicate measurements.

^b Concentrations reported for Run 5 are the average of samples analyzed in triplicate.

^c Two values are given; the first pertains to all five runs and the second pertains to the average of the three optimum runs. (Sediment A = Runs 3, 4, and 5 and Sediment B = Runs 2, 4, and 5.)

Table 7. Triethylamine Concentrations - Treated Solids, Product Water, and Oil Phases

Parameter	Claim	R1	R2	Test Runs ^a		R5	Avg ^c	Standard Deviation ^c
				R3	R4 ^b			
Sediment A								
Triethylamine in Treated Solids (mg/kg)	<150	61.7	93.1	27.8	28.0	79.6	58/45	29.6/29.8
Triethylamine in Product Water (mg/L)	<80	<1	<1	<1	<1	2.2	<2/<2	—
Triethylamine in Oil Phase (%)	NA	—	—	—	—	—	65.8 ^d	—
Sediment B								
Triethylamine in Treated Solids (mg/kg)	<150	106	88.7	55	130	89.3	94/103	27.4/23.7
Triethylamine in Product Water (mg/L)	<80	<1	1.0	<1	<1	<1	<1/<1	NA
Triethylamine in Product Oil (mg/kg)	<1000	—	—	—	—	—	733 ^d	—

^a Concentrations reported for each of the five test runs for each sediment are the average of laboratory triplicate analysis conducted on the sample.

^b Concentrations reported for Run 4 are the average of three field replicate measurements, each of which are the average of laboratory triplicate analysis.

^c Two values are given for treated solids and product water; the first pertains to all five runs and the second pertains to the three optimum runs (Sediment A = Runs 3, 4, and 5; Sediment B = Runs 2, 4, and 5).

^d The % values reported for the Sediment A oil/solvent mixture and the Sediment B product oil are the averages of five aliquot (field replicate) measurements.

demobilization were also excluded from the treatment cost estimate. The reasoning used in making these estimates, or omitting a particular cost category, is discussed in the Applications Analysis Report.

The pilot-scale unit used in this demonstration operated at an average feed rate of 90lbs of contaminated sediment/day. The full-scale commercial unit is projected to be capable of treating 186 tons/day (TPD) of contaminated soil or sludge. The cost estimates are based on the remediation of contaminated soil, sludge or sedi-

ment using the proposed full-scale unit. The treatment cost is estimated to be \$112 /ton if the system is on-line 60% of the time or \$94/ton if the system is on-line 80% of the time. Cost information is presented in the Applications Analysis Report for this demonstration.

Conclusions

The B.E.S.T.[®] solvent extraction process is designed to treat sludges, soils, and sediments contaminated with organic compounds. The system is capable of physically separating organic contami-

nants, such as PAHs, PCBs, and O&G from contaminated media and concentrating the organics for contaminant volume reduction. The prototype full-scale system is only applicable to sludges, but the proposed full-scale system will be applicable to soils and sediments as well.

The effectiveness of treatment can be illustrated from this demonstration and from previous case studies. This demonstration removed at a minimum 96% of the PAHs, greater than 99% of the PCBs, and greater than 98% of the O&G from the contaminated sediments.

The EPA Project Manager, Mark Meckes, is with the Risk Reduction Engineering Laboratory, Cincinnati, OH 45268 (see below)

The complete report, entitled "Technology Evaluation Report: SITE Program Demonstration; Resources Conservation Company Basic Extractive Sludge Treatment (B.E.S.T.®); Grand Calumet River; Gary, Indiana", consists of two volumes:

"Volume I" (Order No. PB93-227122; Cost: \$27.00, subject to change)

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A related report, entitled "Resources Conservation Company, B.E.S.T.®

Solvent Extraction Technology - Applications Analysis Report

(EPA/540/AR-92/079) is available as long as supplies last from:

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