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BIOGENESIS™ Soil Washing Technology

Innovative Technology Evaluation Report





SITE

SUPERFUND INNOVATIVE
TECHNOLOGY EVALUATION

EPA/540/R-93/510
September 1993

BIOGENESIS^{TM} SOIL WASHING TECHNOLOGY

INNOVATIVE TECHNOLOGY EVALUATION REPORT

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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NOTICE

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FOREWORD

The Superfund Innovative Technology Evaluation (SITE) program was authorized by the Superfund Amendments and Reauthorization Act (SARA) of 1986. The program is administered by the EPA Office of Research and Development (ORD). The purpose of the SITE program is to accelerate the development and use of innovative cleanup technologies applicable to Superfund and other hazardous waste sites. This purpose is accomplished through technology demonstrations designed to provide performance and cost data on selected technologies.

This project consisted of a demonstration conducted under the SITE program to evaluate the **BioGenesis™** soil washing technology developed by BioGenesis Enterprises, Inc. The technology demonstration was conducted at an oil refinery site. The demonstration provided information on the performance and cost of the technology. This Innovative Technology Evaluation Report provides an interpretation of the data and discusses the potential applicability of the technology.

A limited number of copies of this report will be available at no charge from EPA's Center for Environmental Research Information, 26 Martin Luther Ring Drive, Cincinnati, Ohio 45268. Requests should include the EPA document number found on the report's cover. When the limited supply is exhausted, additional copies can be purchased from the National Technical Information Service (NTIS), Ravensworth Building, Springfield, Virginia 22161, 703/487-4600. Reference copies will be available at EPA libraries in the Hazardous Waste Collection. You can also call the SITE Clearinghouse hotline at (800) 424-9346 or (202) 382-3000 in Washington, D.C., to inquire about the availability of other reports.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

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This report was prepared under the direction of Ms. Annette Gatchett, the EPA SITE project manager at the Risk Reduction Engineering Laboratory (RREL) in Cincinnati, Ohio. This report was prepared by Dr. Pinaki Banerjee, Mr. Jeff Swano, and Ms. Margaret Flaherty of PRC Environmental Management Inc. (PRC). Contributors and reviewers for this report were Ms. Kim Kreiton and Ms. Laurel Staley of RREL, and Mr. Charles Wilde and Dr. Mohsen Amiran of BioGenesis Enterprises, Inc. The report was typed by Ms. Cheryl Vaccarello, edited by Ms. Deidre Knodell, and reviewed by Dr. Kenneth Partymiller and Dr. David Homer, of PRC.

This report summarizes the findings of an evaluation of the **BioGenesis™** soil washing technology. This technology was developed hy BioGenesis Enterprises, Inc. **(BioGenesis),** to remove organic compounds from soil. This evaluation was conducted under the U.S. Environmental Protection Agency (EPA) Super-fund Innovative Technology Evaluation (SITE) program.

Conclusions from the SITE Demonstration

Based on the SITE demonstrations, the following conclusions may be drawn about the applicability of the **BioGenesis™** soil washing technology:

* Results of chemical analyses for soil samples collected from the refinery site show that levels of total recoverable petroleum hydrocarbons (TRPH), an indicator of degraded crude oil, decreased by 65 to 73 percent in washed soils. After the TRPH in residual soils biodegraded for an additional 120 days, 85 to 88 percent of TRPH was removed from treated soil.

* Results from the SITE demonstration show that the technology can successfully treat soil containing petroleum hydrocarbons. The treatment system's performance was found to be reproducible at constant operating conditions.

* A healthy population of microorganisms capable of degrading petroleum hydrocarbons was found to be present in the treated soil at the refinery. Presence of a healthy population also indicates that the degradation products of petroleum hydrocarbons are probably not toxic to the microorganisms.

* Treatment residuals may require off-site treatment. After washing and biodegradation, treated soils may require disposal at permitted facilities. Wastewater will usually require further treatment. Sediments, if present in appreciable amounts, will require further treatment. For most sites, BioGenesis proposes to recycle wastewater and treat it with its oil/water separator and bioreactor. The **BioGenesis™** wash unit is equipped with carbon filters to treat volatile air emissions, if volatile compounds are present in contaminated soils.

* Results from the treatability study in Santa Maria, California, indicate that for soils contaminated with heavy petroleum hydrocarbons, more than one wash is required for reducing contaminant levels. Treatability studies are highly recommended before large-scale applications of the technology are considered. Because results may vary with different waste characteristics,

the BioGenesis™ treatment system's performance is best predicted with preliminary bench-scale testing.

- The SITE demonstration at the refinery was conducted in temperatures between 30°F and 32°F during periods of rain and light snow. Cold climates adversely impact the effectiveness of biodegradation. Because higher temperatures enhance the effectiveness of biodegradation, warm weather conditions are ideal for operating the BioGenesis™ treatment system.

- The BioGenesis™ treatment system processed crude oil contaminated soil at the refinery at a cost of $74 per cubic yard. Costs at other sites may vary depending on site characteristics.

The BioGenesis™ soil washing technology was evaluated based on the nine criteria used for decision making in the Superfund feasibility study process. Table ES-1 presents the evaluation.

Table ES-l, Evaluation Criteria for the BioGenesis™ Soil Washing Technology

	Criteria								
	Overall Protection of Human Health and the Environment	Compliance with Federal ARARs	Long-Term Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume Through Treatment	Short-Term Effectiveness	Implementability	Cost (1)	Community Acceptance	State Acceptance
Performance	Provides both short- and long-term protection by eliminating exposure to contaminants in soil.	Requires compliance with RCRA treatment, storage, and land disposal regulations (of a haeardous waste).	Effectively removes contamination.	Significantly reduces toxicity, mobility, and volume of soil contaminants through treatment.	Presents potential short-term risks to workers and community, including noise exposure and exposure to contaminants released to air during excavation and handling.	Involves few administrative difficulties.	$74 - $160 per cubic yard	Minimal short-term risks presented to the community make this technology favorable to the public.	If remediation is conducted as part of RCRA corrective actions, state regulatory agencies may require permits to be obtained before implementing the system, such a permit to operate the treatment system, an air emissions permit, and a permit to store contaminated soil for greater than 90 days.
	Prevents further ground-water contamination and off-site migration.	Excavation and construction and operation of on-site treatment unit may require compliance with location-specific ARARs.	Involves well-demonstrated technique for removal of contaminants.	After soil washing, contaminant levels are further reduced by biodegradation.		Used at other sites to address soil contamination.		Biodegradation may require contaminated soils to remain on site for several months, which may be unfavorable to the public.	

Table ES-l. Evaluation Criteria for the BioGenesis” Soil Washing Technology (continued)

	Criteria								
	Overall Protection of Human Health and the Environment	Compliance with Federal ARARs	Long-Tel-m Effectiveness and Permanence	Reduction of Toxicity, Mobility, or Volume Through Treatment	Short-Term Effectiveness	Implementabiity	cost (1)	Community Acceptance	State Acceptance
Performance	Requires measures to protect workers and community during excavation, handling, and treatment.	Emission controls are needed to ensure compliance with air quality standards, if volatile compounds are present.	Involves some residuals treatment (spent carbon, wastewater, sediment) or disposal.			Once on site, the treatment system can be operational within 1 day.			
		Wastewater discharges to POTW or surface water bodies requires compliance with Clean Water Act regulations.				Involves few utility requirements including water, electricity, compressed air, and at some sites, steam.			
		Possible wastewater discharges to under-ground injection wells require compliance with Safe Drinking Water Act regulations.							

Notes:

1 Actual cost of a remediation technology is highly specific and dependent upon the original and target cleanup level, contaminant concentrations, soil characteristics, and volume of soil. Cost data presented in this table are for treating 500 to 2,000 cubic yards of soil.

SECTION 1
INTRODUCTION

This section provides background information about the SITE program, discusses the purpose of this Innovative Technology Evaluation Report (ITER) and describes the **BioGenesis™** soil washing technology. For additional information about the SITE program, this technology, and the demonstration site, key contacts are listed at the end of this section.

1.1 Background

In May 1992, a treatability study of this technology was conducted at a site in Santa Maria, California where soils were contaminated with No. **6** fuel oil, also known as bunker fuel. In November 1992, a demonstration was conducted at a refinery site where soils were contaminated with crude oil. The evaluation of the **BioGenesis™** soil washing technology is based on the results of the SITE demonstration and the treatability study at the two sites.

The BioGenesis™ soil washing technology involves high energy mixing of excavated contaminated soils in a mobile washing unit. The technology consists of a two-stage process. In the first stage, a proprietary solution (BioGenesis™ cleaner) is used to transfer organic compounds from the soil matrix to a liquid phase. The second stage involves biodegradation of residual soil contamination and contaminant-rich wastewater. End products include wastewater, sediments in wastewater, recovered oil or hydrocarbons, and treated soils. Air emissions can also be generated if contaminated soils contain volatile compounds.

The **BioGenesis™** soil washing system has several components: a wash unit, a volatile organic compounds (VOC) emissions hood, holding tanks, oil skimmers, strainers, transfer pumps, an American Petroleum Institute (API) oil/water separator, an oil coalescer, a bioreactor, control panels, and a flat bed trailer for ancillary equipment. Once on site, the treatment system can be in operation within a day if necessary facilities, equipment, utilities, and supplies are available. On-site assembly and maintenance requirements are expected to be minimal. The treatment system can be demobilized and moved off site within 1 day.

1.2 Brief Description of Program and Reports

The SITE program is a formal program established by EPA's Office of Solid Waste and Emergency Response (OSWER) and Office of Research and Development (ORD) in response to the Superfund Amendments and Reauthorization Act of 1986 (SARA). The SITE program promotes the development, demonstration, and use of new or innovative technologies to clean up Superfund sites across the country.

The SITE program's primary purpose is to maximize the use of alternatives in cleaning hazardous waste sites by encouraging the development and demonstration of new, innovative treatment and monitoring technologies. It consists of four major elements discussed below.

The objective of the Demonstration Program is to develop reliable performance and cost data on innovative technologies so that potential users may assess the technology's site-specific applicability. Technologies evaluated are either currently available or close to being available for remediation of Superfund sites. SITE demonstrations are conducted on hazardous waste sites under conditions that closely simulate full-scale remediation conditions, thus assuring the usefulness and reliability of information collected. Data collected are used to assess the performance of the technology, the potential need for pre- and posttreatment processing of wastes, potential operating problems, and the approximate costs. The demonstrations also allow for evaluation of long-term risks and operating and maintenance costs.

The Emerging Technology Program focuses on successfully proven, bench-scale technologies which are in an early stage of development involving pilot or laboratory testing. Successful technologies are encouraged to advance to the Demonstration Program.

Existing technologies which improve field monitoring and site characterizations are identified in the Monitoring and Measurement Technologies Program. New technologies that provide faster, more cost-effective contamination and site assessment data are supported by this program. The Monitoring and Measurement Technologies Program also formulates the protocols and standard operating procedures for demonstrating methods and equipment.

The Technology Transfer Program disseminates technical information on innovative technologies in the Demonstration, Emerging Technology, and Monitoring and Measurements Technologies Programs through various activities. These activities increase the awareness and promote the use of innovative technologies for assessment and remediation at Superfund sites. The goal of technology transfer activities is to develop interactive communication among individuals requiring up-to-date technical information.

Technologies are selected for the SITE Demonstration Program through annual requests for proposals. ORD staff review the proposals to determine which technologies show the most promise for use at Superfund sites. Technologies chosen must be at the pilot- or full-scale stage, must be innovative, and must have some advantage over existing technologies. Mobile technologies are of particular interest.

Once EPA has accepted a proposal, cooperative agreements between EPA and the developer establish responsibilities for conducting the demonstrations and evaluating the technology. The developer is responsible for demonstrating the technology at the selected site and is expected to pay any costs for transport, operations, and removal of the equipment. EPA is responsible for project planning, sampling and analysis, quality assurance and quality control, preparing reports, disseminating information, and transporting and disposing of treated waste materials.

The results of the **BioGenesis™** soil washing technology demonstration are published in two basic documents: the SITE technology capsule and the ITER. The SITE technology capsule provides relevant information on the technology, emphasizing key features of the results of the SITE field demonstration. Both the SITE technology capsule and the ITER are intended for use by remedial managers making a detailed evaluation of the technology for a specific site and waste.

1.3 Purpose of the Innovative Technology Evaluation Report (ITER)

The ITER provides information on the **BioGenesis™** soil washing technology and includes a comprehensive description of the demonstration and its results. The ITER is intended for use by EPA remedial project managers, EPA on-scene coordinators, contractors, and other decision makers for implementing specific remedial actions. The ITER is designed to aid decision makers in further evaluating specific technologies for further consideration as an applicable option in a particular cleanup operation. This report represents a critical step in the development and commercialization of a treatment technology.

To encourage the general use of demonstrated technologies, EPA provides information regarding the applicability of each technology to specific sites and wastes. The ITER includes information on cost and site-specific characteristics. It also discusses advantages, disadvantages, and limitations of the technology.

Each SITE demonstration evaluates the performance of a technology in treating a specific waste. The waste characteristics of other sites may differ from the characteristics of the treated waste. Therefore, successful field demonstration of a technology at one site does not necessarily ensure that it will be applicable at other sites. Data from the field demonstration may require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from a single field demonstration.

1.4 Technology Description

The BioGenesis™ soil washing technology was developed by BioGenesis to treat soil contaminated with organic compounds. According to BioGenesis, the **BioGenesis™** soil washing technology can treat a wide variety of organic contaminants including halogenated solvents, aromatics, gasoline, fuel oils, polychlorinated biphenyls (PCB), and chlorinated phenols. The technology uses a proprietary solution (**BioGenesis™** cleaner) to transfer organic compounds from the soil matrix to the liquid phase. The proprietary ingredient is an alkaline, organic surfactant.

According to the developer, **BioGenesis™** cleaner is rapidly biodegraded by common soil microbes. The **BioGenesis™** cleaner stimulates microbial activity, which biodegrades residual soil contamination not removed by the wash solution. According to the material safety data sheet (MSDS) provided by BioGenesis, none of the constituents of the surfactant are defined as a RCRA or CERCLA hazardous waste or hazardous constituent. BioGenesis claims that contaminant-rich wastewater is also amenable to biodegradation in aerated reactors.

In general, soils containing sand and other coarse materials are the most ideal for soil washing treatment technologies. Although contaminants in silty and clayey soils are usually strongly sorbed and difficult to remove, BioGenesis claims that its technology is effective for silty soils and soils with high clay concentrations.

BioGenesis claims that in most cases, the BioGenesis™ soil washing technology can reduce concentrations of certain soil contaminants from up to 45,000 parts per million (ppm) to below laboratory detection levels. The end products of the soil washing process are treated soil, contaminated wastewater, sediment in wastewater, and an oil/solvent phase. Contaminated wastewater is transferred to an aerated reactor for 24 hours to allow contaminants to biodegrade before discharge. Treated soil is stored in roll-off bins, and the contaminants are allowed to biodegrade prior to disposal. The oil/solvent phase is recovered for off-site disposal or reuse.

A schematic of the **BioGenesis™** treatment system is shown in Figure 1-1. The major components of the system include the following:

- Washing unit. This is the principal component of the treatment system. The unit is 24 feet long, 7 feet wide, and 5 feet deep, with overflow channels 1 foot deep. The unit has a perforated base to introduce air for mixing and to drain wastewater. It is equipped with a shaker mechanism (three units on each side of the wash unit) for agitating the soil slurry to enhance mixing. A canvas hood covers the top of the wash unit to contain any organic compounds volatilized during treatment and prevent discharge to the atmosphere.

- Bioreactor. The bioreactor is a cylindrical tank with a holding capacity of approximately 5,000 gallons. At the end of the demonstration, wastewater from the oil/water separators is transferred to the bioreactor. The specially formulated **BioGenesis™** cleaner is added to the bioreactor to stimulate biodegradation of residual contamination in the wastewater. Within the bioreactor, water is mixed by pumping it through a spray aerator fitted above the liquid phase.

- Oil skimmers. In Holding Tank 2, oil is skimmed from the surface of the soil and water mixture. A mechanical method uses rising water which pushes the oil/water into a system that runs through a belt. Oil clings to the belt and is removed.

- Strainers. Strainers are located at the ends of the oil skimmer troughs on the wash unit. The strainers prevent floating solids from entering the transfer pump.

- Two 7.5-horsepower (hp) transfer pumps and hoses. These pumps transfer wastewater from the wash unit to the baffle separator.

- API oil/water separator. This unit is used as a primary separator to separate oil from the wastewater. Recovered oil is transferred to oil storage drums, and the wastewater is recycled to the wash unit.

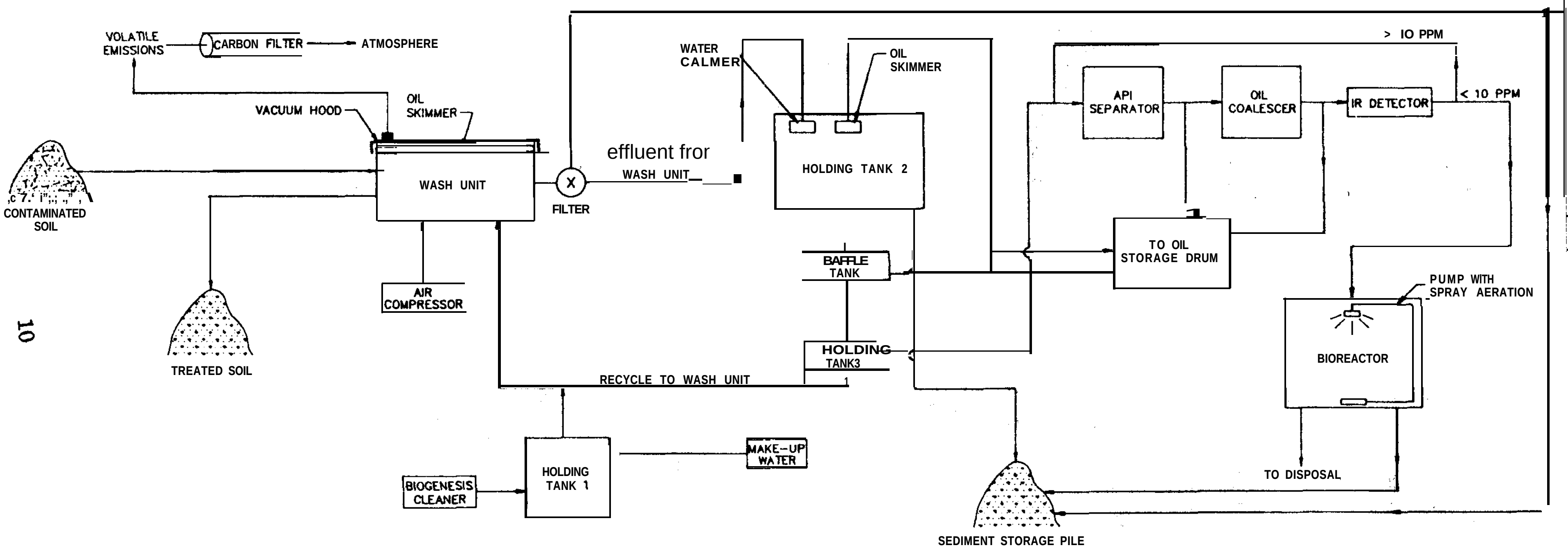

Figure I-I. Biogenesis soil washing process.

- Oil coalescer. This unit is used as a secondary separator to separate the oil/solvent phase from the wastewater. The unit is equipped with an infra-red (IR) detector to monitor total petroleum hydrocarbon (TPH) concentrations. The detector controls a diversion valve that, depending on TPH concentration in the water, either returns the water to the API separator or to the bioreactor.

- One 48-foot flat bed trailer. This trailer houses a 200-ampere (amp), 480-volt, three-phase generator; three 25-hp, air-cooled air compressors; a vacuum pump; an activated-charcoal filter used to treat air emissions from the wash unit; and API separator, bioreactor, and the oil coalesce;.

The **BioGenesis™** process begins by introducing contaminated soil into the wash unit, usually with a front-end loader. The wash unit can treat 20 cubic yards of soil per batch. After the wash unit is loaded with soil, three shaker mechanisms on each side of the unit are activated. If VOCs are present, the wash unit is covered with a retractable canvas. A positive air flow is drawn through the back of the wash unit, creating negative pressure within the unit to strip away any VOCs. Volatile emissions, if any, are passed through a granular activated carbon filter before being vented to ambient air.

Water and **BioGenesis™** cleaner are premixed in a 4,800-gallon holding tank (Holding Tank 1) and pumped into the wash unit. During the SITE demonstration, a typical wash required approximately 4,000 gallons (15,000 liters) of water and 7 to 8 gallons of **BioGenesis™** cleaner. The resulting soil slurry is agitated by the shaker mechanisms and a series of aerators in the bottom of the wash unit. After the soil slurry is mixed for a period of time (approximately 30 to 45 minutes) determined by the developer, air is turned off. Water is then added to raise the fluid level, allowing floating oil product to flow out of the unit via ports (0.125-inch mesh screen) located 8 inches from the top of the unit and into another holding tank (Holding Tank 2). After the floating product is removed, the soil slurry is agitated again for a period determined by the developer. The fluid level is again raised to allow oil and water to be removed through the ports. Soil settles to the bottom of the wash unit. Water percolates through the soil and drains through perforations in the bottom of the wash unit. Wash water from the bottom of the wash unit and oil and water exiting through the ports are pumped to Holding Tank 3, which is equipped with an oil skimmer. After the water has drained from the treated soil, the operator inverts one end of the wash unit, dumping the soil onto a bermed area covered with plastic sheeting. Treated soils are transferred from the bermed area into storage bins with an approximate capacity of 20 cubic yards using a front-end loader. Soils in the storage bins are covered with plastic sheets pending results of laboratory analyses.

In Holding Tank 3, the oily material removed by the skimmer is pumped to 55-gallon drums. Material not removed by skimming is pumped to the API separator. Any oily material recovered from the API separator is pumped to 55-gallon drums. Water from the API separator is then directed to Holding Tank 1 for storage prior to reuse in the wash unit. About 10 to 15 percent of the wash water is retained in the soil; therefore, make-up water and BioGenesis™ cleaner must be added to the recycled water as needed. Any make-up water required to wash the next batch of soil is supplied from Holding Tank 2.

Once all runs are complete, the water in Holding Tank 3 is processed through the oil/ water separation unit, which includes the API separator and the oil coalescer. Water from the coalescer is monitored by an IR detector for TPH and is directed to a bioreactor if the TPH concentration is below 50 ppm. If the TPH concentration is above 50 ppm, the water is recycled through the API separator and coalescer until the TPH concentration is below 50 ppm. Oily material from the coalescer is pumped to 55-gallon drums. Sediments from the wash unit, Holding Tank 3, and the bioreactor are stored in storage bins and covered with plastic sheets. Samples from the treated soil storage bins are collected over a period of time and analyzed for chemical composition. After 24 hours, effluent from the bioreactor is pumped to a holding tank.

At the refinery site, BioGenesis did not use the holding tanks, the API separator, the oil coalescer, or the bioreactor. The treatment system, as used at this site, is shown in Figure l-2. Water needed for soil washing was supplied by the refinery and was not recycled. BioGenesis used steam to raise the temperature of the wash water to 80°C. Wastewater from the unit was pumped to a 20,000-gallon settling tank and then pumped to the refinery's wastewater treatment system which is equipped with oil/water separators. A bioreactor was not used to further reduce contaminant levels. Instead of roll-off bins, treated soil was placed in a soil pile.

1.5 Key Contacts

Additional information on the BioGenesis™ soil washing technology and the SITE program can be obtained from the following sources:

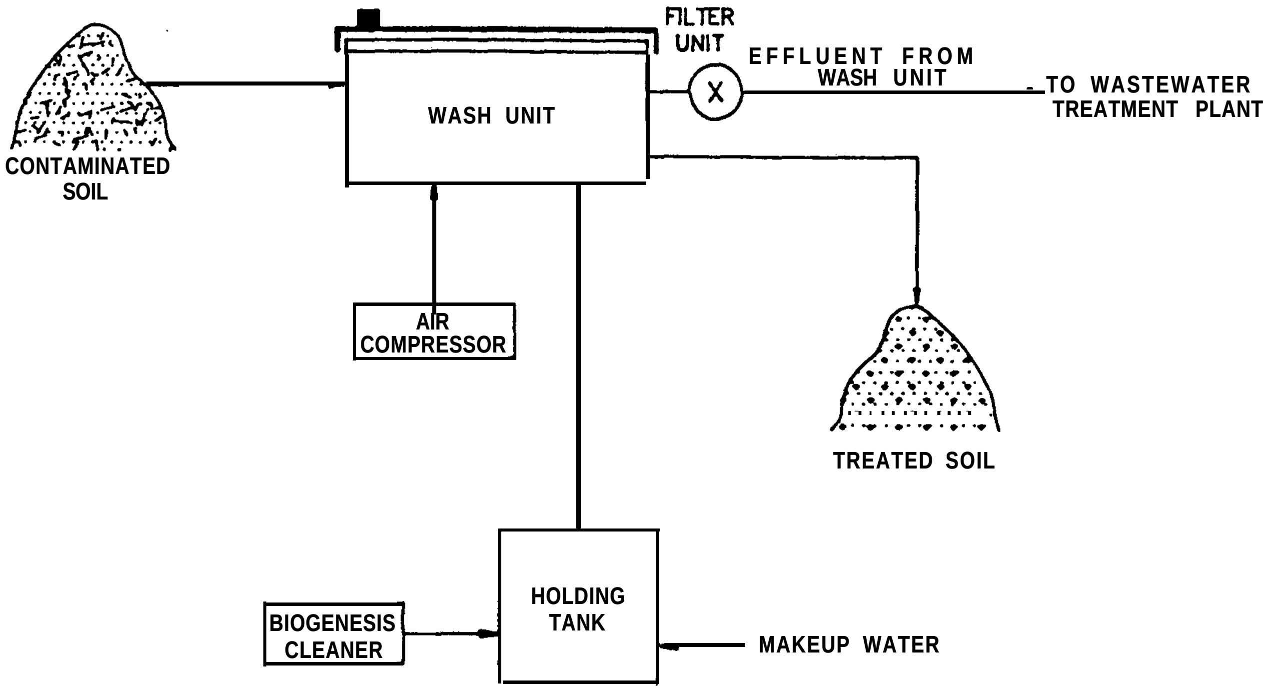

Figure I-2. Biogenesis soil washing process during SITE demonstration.

The **BioGenesis™** Soil Washing Technology

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Information on the SITE program is available through the following on-line information clearinghouses:

* The Alternative Treatment Technology Information Center (ATTIC) System (operator: 301-670-6294) is a comprehensive, automated information retrieval system that integrates data on hazardous waste treatment technologies into a centralized, searchable source. This data base provides summarized information on innovative treatment technologies.

* The Vendor Information System for Innovative Treatment Technologies (VISITT) (Hotline: 800-245-4505) data base contains information on 154 technologies offered by 97 developers.

* The OSWER CLU-In electronic bulletin board contain information on the status of SITE technology demonstrations. The system operator can be reached at 301-585-8368.

Technical reports may be obtained by contacting the Center for Environmental Research Information (CERI), 26 W. Martin Luther King Drive in Cincinnati, OH 45268 at 513-569-7562

SECTION 2
TECHNOLOGY APPLICATIONS ANALYSIS

This section of the report addresses the general applicability of the BioGenesis™ soil washing technology to contaminated waste sites. The analysis is based primarily on the SITE treatability study and demonstration results since limited information was available on other applications of the technology.

2.1 Objectives - Performance versus ARARs

This subsection discusses specific environmental regulations pertinent to the operation of the BioGenesis™ soil washing system, including the transport, treatment, storage, and disposal of wastes and treatment residuals and analyzes these regulations in view of the demonstration results. State and local regulatory requirements, which may be more stringent, will also have to be addressed by remedial managers. Applicable or relevant and appropriate requirements (ARARs) include the following: (1) the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); (2) the Resource Conservation and Recovery Act (RCRAI; (3) the Clean Air Act (CAA); (4) the Safe Drinking Water Act (SDWA); (5) the Toxic Substances Control Act (TSCA); and (6) the Occupational Safety and Health Administration (OSHA) regulations. These six general ARARs are discussed below; specific ARARs must be identified by remedial managers for each site. Some specific federal and state ARARs which may be applicable to the BioGenesis™ soil washing technology are identified and discussed in Table 3-l.

2.1.1 Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA authorizes the Federal government to respond to releases or potential releases of any hazardous substance into the environment, as well as to releases of pollutants or contaminants that may present an imminent or significant danger to public health and welfare or the environment.

As part of the requirements of CERCLA, EPA has prepared the National Contingency Plan (NCP) for hazardous substance response. The NCP is codified in Title 40 Code of Federal Regulations (CFR) Part 300, and delineates the methods and criteria used to determine the appropriate extent of removal and cleanup for hazardous waste contamination.

Table 2-1. Federal and State ARARs for the BioGenesis™ Soil Washing Technology

Process Activity	ARAR	Description	Basis	Response
Waste characterization (untreated waste)	RCRA 40 CFR Part 261 or state equivalent	Identifying and characterizing the waste as treated	A requirement of RCRA prior to managing and handling the waste	Chemical and physical analyses must be performed.
	TSCA 40 CFR Part 761 or state equivalent	Standards that apply to the treatment and disposal of wastes containing PCBs	During waste characterization, PCBs may be identified in contaminated soils, and are therefore subject to TSCA regulations	Chemical and physical analyses must be performed. If PCBs are identified, soils will be managed according to TSCA regulations.
Soil excavation	Clean Air Act 40 CFR 50.6, and 40 CFR 52 Subpart K or state equivalent	Management of toxic pollutants and particulate matter in the air	Fugitive air emissions may occur during excavation and material handling and transport.	If necessary, the waste material should be watered down or covered to eliminate or minimize dust generation.
	RCRA 40 CFR Section 262 or state equivalent	Standards that apply to generators of hazardous waste	The soils are excavated for treatment.	If possible soils should be fed directly into the wash unit for treatment.
Storage prior to processing	RCRA 40 CFR Part 264 or state equivalent	Standards applicable to the storage of haeardous waste	Excavation may generate a hazardous waste that must be stored in a waste pile.	If in a waste pile, the material should be placed on and covered with plastic and tied down to minimize fugitive air emissions and volatilization. The time between excavation and treatment should be kept to a minimum.
Waste processing	RCRA 40 CFR Parts 264 and 265 or state equivalent	Standards applicable to the treatment of hazardous waste at permitted and interim status facilities	Treatment of hazardous waste must be conducted in a manner that meets the operating and monitoring requirements; the treatment process occurs in a tank.	Equipment must be operated and maintained daily. Tank integrity must be monitored and maintained to prevent leakage or failure; the tank must be decontaminated when processing is complete. Air emissions must be characterized by continuous emissions monitoring.
Storage after processing	RCRA 40 CFR Part 264 or state equivalent	Standards that apply to the storage of hazardous waste in containers	The treated soil will be placed in tanks prior to a decision on final disposition.	The treated soils must be stored in containers that are well maintained; container storage area must be constructed to control runon and runoff.
Waste characterization (treated waste)	RCRA 40 CFR Part 261 or state equivalent	Standards that apply to waste characteristics	A requirement of RCRA prior to managing and handling the waste; it must be determined if treated soil is RCRA hazardous waste.	Chemical and physical tests must be performed on treated soils prior to disposal.
	TSCA 40 CFR Part 761 or state equivalent	Standards that apply to the treatment and disposal of wastes containing PCBs	Soils treated may still contain PCBs	Chemical and physical tests must be performed on treated soils. If PCBs are identified, a proper disposal method will be selected.

Table 2-l. Federal and State ARARs for the BioGenesis™ Soil Washing Technology (continued)

Process Activity	ARAR	Description	Basis	Response
On-site/off-site disposal	RCRA 40 CFR Part 264 or state equivalent	Standards that apply to landfilling hacardous waste	Treated soils may still contain contaminants in levels above required cleanup action levels and therefore be subject to LDRs.	Treated wastes must be disposed of at a RCRA-permitted hazardous waste facility, or approval must be obtained from EPA to dispose of the wastes on site.
	TSCA 40 Part 761 or state equivalent	Standards that restrict the placement of PCBs in or on the ground	Treated soils containing less than 500 ppm PCB may be landfilled or incinerated.	If untreated soil contained PCBs, then treated soil should be analyred for PCB concentration. Approved PCB landfills or incinerators must be used for disposal.
	RCRA 40 CFR Part 268 or state equivalent	Standards that restrict the placement of certain wastes in or on the ground	The nature of the waste may be subject to the LDRs.	The waste must be charactericed to determine if the LDRs apply; treated wastes must be tested and results compared.
	SARA Section 121(d)(3)	Requirements for the off-site disposal of wastes from a Superfund site	The waste is being generated from a response action authorieed under SARA.	Wastes must be disposed of at a RCRA-permitted haeardous waste facility.
Transportation for off-site disposal	RCRA 40 CFR Part 262 or state equivalent	Manifest requirements and packaging and labeling requirements prior to transporting	The treated soil may need to be manifested and managed as a hacardous waste.	An identification (ID) number must be obtained from EPA.
	RCRA 40 CFR Part 263 or state equivalent	Transportation standards	Treated soil may need to be transported as a hazardous waste.	A transporter licensed by EPA must be used to transport the hacardous waste according to EPA regulations.
Wastewater discharge	Clean Water Act 40 CFR Parts 301, 304, 306, 307, 308, 402, and 403	Standards that apply to discharge of wastewater into sewage treatment plant or surface water bodies	The wastewater may be a haeardous waste.	Determine if wastewater could be directly discharged into a sewage treatment plant or surface water body. If not, the wastewater may need to be further treated to meet discharge requirements by conventional processes.
	Safe Drinking Water Act 40 CFR Parts 144 and 145	Standards that apply to the disposal of contaminated water in underground injection wells	Wastewater may require disposal in underground injection wells.	If underground injection is selected as a disposal means for contaminated wastewater, permission must be obtained from EPA to use existing permitted underground injection wells, or to construct and operate new wells.

Superfund Amendments and Reauthorization Act (SARA) amended CERCLA, directing EPA to do the following:

- Use remedial alternatives that permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances, pollutants, or contaminants
- Select remedial actions that protect human health and the environment, are cost-effective, and involve permanent solutions and alternative treatment or resource recovery technologies to the maximum extent possible
- Avoid off-site transport and disposal of untreated hazardous substances or contaminated materials when practicable treatment technologies exist (Section 121(b)).

In general, two types of responses are possible under CERCLA: removals and remedial actions. The **BioGenesis™** soil washing technology is likely to be part of a CERCLA remedial action. Since 1986, various soil washing technologies were selected as source control remedies at eight Superfund sites.

Remedial actions are governed by the SARA amendments to CERCLA. As stated above, these amendments promote remedies that permanently reduce the volume, toxicity, and mobility of hazardous substances, pollutants, or contaminants. In general, soil washing technologies only transfers contaminants from one media to another.contaminant volume. However, BioGenesis claims that its cleaner stimulates the biodegradation of soil contaminants, and thus reduces both contaminant volume and toxicity.

On-site remedial actions must comply with federal and more stringent state ARARs. ARARs are determined on a site by site basis and may be waived under six conditions: (1) the action is an interim measure, and the ARAR will be met at completion; (2) compliance with the ARAR would pose a greater risk to health and the environment than noncompliance; (3) it is technically impracticable to meet the ARAR; (4) the standard of performance of an ARAR can be met by an equivalent method; (5) a state ARAR has not been consistently applied elsewhere; and (6) ARAR compliance would not provide a balance between the protection achieved at a particular site and demands on the Superfund for other sites. These waiver options apply only to Superfund actions taken on site, and justification for the waiver must be clearly demonstrated.

2.1.2 Resource Conservation and Recovery Act

RCRA, an amendment to the Solid Waste Disposal Act (SWDA), was passed in 1976 to address the problem of how to safely dispose of the enormous volume of municipal and industrial solid waste generated annually. RCRA specifically addressed the identification and management of hazardous wastes. The Hazardous and Solid Waste Amendments of 1984 (HSWA) greatly expanded the scope and requirements of RCRA.

The presence of RCRA defined hazardous waste determines whether RCRA regulations apply to the **BioGenesis™** soil washing technology. If soils are determined to be hazardous according to RCRA, all RCRA requirements regarding the management and disposal of hazardous wastes will need to be addressed. RCRA regulations define hazardous wastes and regulate their transport, treatment, storage, and disposal. Wastes defined as hazardous under RCRA include characteristic and listed wastes. Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261 Subpart C. Listed wastes from nonspecific and specific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261 Subpart D.

Once contaminated soils are treated by the **BioGenesis™** treatment system, the treated soils may still contain hazardous constituents at levels above required cleanup action levels. Such soils need to be managed as hazardous waste and are subject to land disposal restrictions (LDR) under both RCRA and CERCLA. Applicable RCRA requirements could include a Uniform Hazardous Waste Manifest if the treated soils are transported, restrictions on placing the treated soils in land disposal units, time limits on accumulating treated soils, and permits for storing treated soils.

Requirements for correction action at RCRA-regulated facilities are provided in 40 CFR Part 264, Subpart F (promulgated) and Subpart S (proposed). These subparts also generally apply to remediation at Superfund sites. Subparts F and S include requirements for initiating and conducting RCRA corrective actions, remediating ground water, and ensuring that corrective actions comply with other environmental regulations. Subpart S also details conditions under which particular RCRA requirements may be waived for temporary treatment units operating at corrective action sites. Thus, RCRA mandates requirements similar to CERCLA, and as proposed, allows treatment units such as the **BioGenesis™** treatment system to operate without full permits,

2.1.3 Clean Air Act

The CAA requires that treatment, storage, and disposal facilities comply with primary and secondary ambient air quality standards. During the excavation, transportation, and treatment of soils, fugitive emissions are possible. Steps must be taken to prevent or minimize the impact from fugitive emissions, such as watering down the soils, or covering them with industrial strength plastic prior to treatment. The **BioGenesis™** wash unit is equipped with carbon filters to treat volatile emissions, if volatile compounds are present in the soils. State air quality standards may require additional measures to prevent fugitive emissions.

2.1.4 Safe Drinking Water Act

The SDWA of 1974, as most recently amended by the Safe Drinking Water Amendments of 1986, requires EPA to establish regulations to protect human health from contaminants in drinking water. The legislation authorizes national drinking water standards and a joint Federal-state system for ensuring compliance with these standards.

The National Primary Drinking Water Standards are found in 40 CFR Parts 141 through 149. Parts 144 and 145 discuss requirements associated with the underground injection of contaminated water. Wastewater generated by the **BioGenesis™** treatment system may be disposed of in permitted underground injection wells. During the treatability study, wastewater generated by the **BioGenesis™** treatment system was disposed of underground. If injection of wastewater is selected as a disposal means for wastewater generated during the soil washing process, approval from EPA for constructing and operating a new underground injection wells is required. A permit will not be required if an existing permitted underground injection well is accessible.

2.1.5 Toxic Substances Control Act

The disposal of PCBs is regulated under Section 6(e) of the Toxic Substances Control Act of 1976 (TSCA). PCB treatment and disposal regulations are described in 40 CFR Part 761. Materials containing PCBs in concentrations between 50 and 500 ppm may either be disposed of in TSCA-permitted landfills or destroyed by incineration at a TSCA-approved incinerator; at concentrations greater than 500 ppm, the material must be incinerated. Therefore, soil contaminated with up to 500 ppm of PCBs may be suitable for the **BioGenesis™** soil washing technology. Where individual state standards are stricter than federal standards, **BioGenesis™** may be unacceptable as a pre-disposal remedy.

Sites where spills of PCBs have occurred after May 4, 1987, must be addressed under the PCB Spill Cleanup Policy in 40 CFR Part 761, Subpart G. In order to meet the requirements under the spill cleanup policy, wastes slated for treatment using the **BioGenesis™** soil washing technology may require additional treatment, if the PCB spill cleanup standards are not met. The policy applies to spills of materials containing 50 ppm or greater PCBs and establishes cleanup protocols for addressing such releases based upon the volume and concentration of the spilled material.

2.1.6 Occupational Safety and Health Administration Requirements

CERCLA remedial actions and RCRA corrective actions must be performed in accordance with OSHA requirements detailed in **20 CFR** Parts 1900 through 1926, especially Part 1910.120, which provides for the health and safety of workers at hazardous waste sites. On-site construction activities at Superfund or RCRA corrective actions sites must be performed in accordance with Part 1926 of OSHA, which provides safety and health regulations for constructions sites. State OSHA requirements, which may be significantly stricter than Federal standards, must also be met.

All technicians operating the **BioGenesis™** treatment system are required to have completed an OSHA training course and must be familiar with all OSHA requirements relevant to hazardous waste sites. For most sites, minimum personal protective equipment (PPE) for technicians will include gloves, hard hats, steel toe boots, and coveralls. Depending on contaminant types and concentrations, additional PPE may be required. Noise levels should be monitored to ensure that workers are not exposed to noise levels above a time-weighted average of 85 decibels over an 8-hour day. If operation of the **BioGenesis™** treatment system causes noise levels to increase above this limit, then workers will be required to wear ear protection.

2.1.7 Technology Performance versus ARARs during the Demonstration

Several ARARs discussed in Table 2-1 did not apply to the **BioGenesis™** soil washing technology during the demonstration at the refinery site. ARARs relevant to soil excavation were not applicable during the demonstration because soils at the refinery had been excavated previously and stockpiled in the decontamination area. In addition, plastic was not required under the stockpiled soil. Rather, runoff from the decontamination area was controlled by a concrete base equipped with drains that discharged directly to the on-site wastewater treatment plant. ARARs relevant to underground injection wells also did not apply because all wastewater was discharged to the on-site wastewater treatment plant before discharge to a publicly-owned treatment works (POTW) facility. After treatment, the soil was again stockpiled in the decontamination area to biodegrade for about 1 year.

Because volatile compounds were not present in soils at the refinery, the soils did not need to be watered down or covered with plastic. Treated soil at the refinery was not hazardous as defined by RCRA or state regulations. Therefore, ARARs applicable to the disposal of hazardous wastes were not applicable to the refinery site demonstration. Because treated soils were allowed to biodegrade, BioGenesis expects that the TRPH in the soil will eventually decrease to levels that will meet local requirements for reusing the soil as fill material.

If sites are not equipped with a container storage area adequate to prevent runon and runoff, treated soils may be placed on plastic and surrounded by a berm, or placed in roll-off bins. If soils are to be disposed of off site, disposal costs will vary according to contaminant concentrations in the soil.

2.2 Operability of the Technology

The BioGenesis treatment system consists of the wash unit and other support equipment described in Section 1.3. The wash unit, a specially designed mobile unit, is operated by BioGenesis personnel. The wash unit appeared free of operational problems during the demonstration at the refinery.

Several operating parameters influence the performance of the **BioGenesis™** treatment system. Its performance is most affected by the amount of time necessary for contaminants to move from the soil matrix to wastewater (mixing time) and by the concentration of the BioGenesis™ cleaner. If the mixing time is reduced too much, efficiency of the contaminant transfer will be reduced. If the mixing time is increased too much, time to treat soil increases, affecting the cost. Similarly, a low dose of **BioGenesis™** cleaner may reduce contaminant transfer, while a high dose will not be cost effective. BioGenesis determined the preferred values for these parameters during treatment of approximately 1,000 cubic yards of soil at the refinery site prior to the demonstration. Another operating parameter that may affect soil washing is air pressure.

Air is used by BioGenesis to enhance mixing. Air pressure is controlled by BioGenesis at a preferred rate determined by professional judgment.

Depending upon contaminant type and soil characteristics, each batch of soil may require one or more washes. At the refinery site, where the contaminant was crude oil, BioGenesis washed each batch of soil twice. While increasing the number of washes results in additional cost and time required to process soil, it also increases the amount of contaminants transferred from soil to wastewater. Also, depending upon contaminant type and climate, temperature of the soil slurry may need to be raised. Steam can be used to raise temperatures of wash water prior to its introduction into the wash unit.

In addition to the wash unit, other components of the BioGenesis™ treatment system include the VOC emission hood, the holding tanks, the API separator, the oil coalescer, and the bioreactor. If the soil contains VOCs, then the emission hood and a carbon filter system are used to reduce air emissions. Two holding tanks store wash water and recycle water. A third holding tank is used for settlement of suspended particulates in wastewater. The API separator and the oil coalescer separate and recover oily contaminants from the wastewater. The bioreactor allows biodegradation of wastewater. At the refinery, none of these components was used since the soil had low levels of VOCs, wastewater was not recycled, and wastewater was treated by the refinery.

The holding tanks and an oil/water separator were tested during the treatability studies in Santa Maria. The oil skimmers associated with the holding tanks performed poorly, allowing excessive amounts of oil to reach the separator. As a result, the oil/water separator was overloaded and did not function properly. According to BioGenesis, the oil skimmers have since been redesigned.

To enhance biodegradation of residual contamination, BioGenesis adds additional surfactant solution to the treated soil. Treated soil can be stored in roll-off bins or in a soil pile. Climatic conditions affect further biodegradation; in cold climates, the rate of biodegradation is lower than in warm climates.

The SITE demonstration was planned to treat 64 cubic yards of soil in four runs. Due to sampling problems, data from only three runs were considered valid. However, each run consisted of 18 cubic yards of soil, so that a total of 54 cubic yards of soil was processed over a 3-day period.

2.3 Applicable Wastes

BioGenesis claims that the BioGenesis™ soil washing technology extracts volatile, semivolatile, and nonvolatile hydrocarbons, including halogenated solvents, aromatics, gasoline, fuel oils, PCBs, and chlorinated phenols from most soils. Results from the treatability study conducted in Santa Maria, California indicate that for soils contaminated with heavy petroleum hydrocarbons, more than one wash is required for reducing contaminant levels. Residual contaminants in soil and wastewater is further removed through biodegradation. According to BioGenesis, its technology is capable of treating soil contaminated with both organic compounds and metals. However, this SITE demonstration was designed to evaluate organics removal only. It should be noted that high concentrations of certain metals, such as lead and mercury may be toxic to microorganisms involved in biodegradation of organics.

BioGenesis claims that this process can successfully treat soils with petroleum hydrocarbons in concentrations up to 45,000 ppm. Analytical results for untreated soils at the refinery showed that the highest concentration of TRPH was 11,000 ppm.

In general, soils containing sand and other coarse materials are the most ideal for treatment by soil washing technologies. BioGenesis claims that this technology is also effective for silty soils and soils with high clay concentrations. However, soils at the refinery were sandy and, therefore, did not allow verification of BioGenesis' claim. Although the wash unit can handle large particles, for monitoring purposes, particles larger than 2 inches in diameter should be screened out.

2.4 Key Features of the BioGenesis™ Soil Washing Technology

The BioGenesis™ soil washing technology has several unique features that distinguish it from most soil washing techniques. The wash unit is specially designed with a shaker system, a VOC emission control system, and an air injection system. According to BioGenesis, the proprietary BioGenesis™ cleaner aids transfer of contaminants from the soil matrix to wastewater and enhances biodegradation of residual contaminants in soil and wastewater.

2.5 Availability and Transportability of Equipment

The **BioGenesis™** wash unit and support equipment are mounted on flat-bed trailers and are easily transported. Once on site, the treatment system can be in operation within a day if all necessary facilities, utilities, and supplies are available. On-site assembly and maintenance requirements are minimal. Demobilization activities include decontaminating on-site equipment disconnecting utilities, disassembling equipment, and transporting equipment off site. Currently BioGenesis has one wash unit, along with the support equipment, available and is acquiring another wash unit. The proprietary **BioGenesis™** cleaner is available through BioGenesis.

2.6 Materials Handling Requirements

At most sites, contaminated soil will need to be excavated, staged, transported, and loaded into the wash unit. Soils should be kept wet if fugitive emissions of particulates are expected. Also, most VOCs, if present in the soil, will volatilize into the atmosphere. At sites where VOCs are the primary contaminants, soil should be handled within an enclosed system. At the conclusion of each wash, treated soil is placed on the ground. Treated soil may contain an appreciable amount of moisture and requires runoff control measures.

At some sites, water needed for washing may be available from the facility or the local water source; at other sites wash water may need to be transported in water trucks. Wash water may require special handling if steam is used to raise the temperature of the water.

Wastewater is skimmed off the top of the wash unit and is pumped either to a holding tank or, if available, to the facility's wastewater treatment plant. Care should be taken to ensure that wastewater is not spilled during transfer from the wash unit or during storage. Special care should also be taken during processing of wastewater through the API separator and the oil coalescer. Large amounts of fine particles in the wastewater may affect operation of the separator and the coalescer by blocking the flow of wastewater.

2.7 Site Support Requirements

Technology support requirements include utilities, support facilities, and support equipment. These requirements are discussed below.

Utilities required for the BioGenesis™ treatment system include water, electricity, and, at some sites, steam. Water is needed to operate the wash unit and to decontaminate equipment. BioGenesis requires approximately 19,400 liters of water per wash. If water cannot be recycled at a particular site, water requirements could be large. The BioGenesis™ treatment system requires one 200-ampere, 480-volt, triple phase electrical circuit. BioGenesis has a generator that meets these power requirements. However, the generator can be very noisy, and, at sites with nearby residential communities, an alternate source of electricity must be found. At some sites, depending on contaminant characteristics, steam may be required to raise the temperature of the soil slurry. BioGenesis usually arranges for the hot water service.

Support facilities include a contaminated soil staging area, a treated soil storage area, and a drum storage area. Treated soil and sediments could be stored in roll-off bins or soil piles. Drums containing recovered oil and hydrocarbons must be stored in the drum storage area. In addition, a tank storage area to store wastewater may be required at some sites. These support facilities must be contained to control runon and runoff.

Support equipment for the BioGenesis™ treatment system includes earth-moving equipment, forklifts, containers for recovered hydrocarbons, containers for treated soils and sediments, and a container for wastewater. Earth-moving equipment, including backhoes, front-end loaders, and at some sites, dump trucks, are needed to excavate and move soils to the wash unit. Forklifts are needed to move drums.

Accurately determining the amount of soil treated may be required at some sites. Determining the mass of soil treated was difficult during the treatability studies at the Santa Maria site. Different types of scales, including bucket scales and platform scales, were found to be inappropriate for weighing front-end loaders. However, a semiqualitative estimate of the volume of soil treated was made. Flow meters are required to measure the volume of water and wastewater.

2.8 Limitations of the Technology

In general, soil washing technologies only reduce contaminant volume. Because the BioGenesis process uses both soil washing and biodegradation, however, reduction in contaminant mass, toxicity, and volume reduction are expected.

Contaminants in silty or clayey soils are usually strongly sorbed and difficult to remove, and soil washing technologies are generally ineffective. BioGenesis claims that its process is effective in soils with high clay concentrations. Soils treated at the refinery were sandy in nature with 5% silt and 6% clay content.

According to BioGenesis, its technology is capable of treating soil contaminated with both organic compounds and metals. However, this SITE demonstration was designed to evaluate organics removal only. It should be noted that high concentrations of certain metals may be toxic to microorganisms involved in biodegradation of organics. Cold climates may also adversely affect the rate of biodegradation.

During the treatability studies in Santa Maria, California, BioGenesis treated soils contaminated with bunker fuel, the heavy end of the petroleum distillation process. Results of chemical analysis indicated low removal efficiencies after soil washing. Removal efficiencies improved when the same batch of soil was washed twice. Biodegradation studies conducted in a laboratory showed minimal reduction in contaminant levels after 60 days. BioGenesis has since modified the wash unit to optimize mixing and extracting efficiencies.

SECTION 3
ECONOMIC ANALYSIS

This section presents cost estimates for operating the BioGenesis™ soil washing technology. Cost data was compiled during SITE treatahility study at the Santa Maria Health Care facility (Santa Maria) in Santa Maria, California, and at an oil refinery site. Costs have been placed in 12 categories applicable to typical cleanup activities at Superfund and RCRA sites (Evans, 1990). Costs are presented in February 1993 dollars and are considered to be estimates, with an accuracy of plus 50 percent and minus 30 percent.

This economic analysis shows that operating costs are most affected by the amount of site preparation needed and whether the treated soil can be backfilled at the site or requires off-site disposal. In addition, the quantity of soil to be treated and the nature and concentration of contaminants affects the duration of a soil remediation project and the amount of materials necessary for all aspects of the remediation.

3.1 Conclusion of Economic Analysis

This analysis presents the costs of treating 1,000 cubic yards of soil contaminated with TRPH. Table 3-l presents a breakdown of costs into the 12 cost categories. The table presents total fixed and total variable costs and the costs per cubic yard of soil treated. It also estimates the costs of treating 500 and 2,000 cubic yards of soil under the same conditions.

Total estimated one-time costs are about $61,000. Of this, $10,000, or about 16 percent, is the price of retaining the soil washing service from BioGenesis; and $22,000, or 36 percent of fixed costs, is for site preparation. Total estimated variable costs are $41,000. Of this, $24,000, or 60 percent of total variable costs, is for residual and waste disposal. These factors have the greatest influence on the total cost of the project because site and soil conditions greatly affect these costs. In addition, the amount of soil and the contaminant concentrations significantly impact the duration and costs of a soil remediation project. The estimated cost per cubic yard of soil for treating 1,000 cubic yards of soil is $103.

Table 3-1. **Costs Associated with the BioGenesis™ Soil Washing Technology** [a]

Cost Categories	Volume of Soil Treated (cubic yards)		
	500	1,000	2,000
Site Preparation [b]	**$20,800**	**$22,300**	**$24,200**
Permitting and Regulatory Requirements [b]	**10,000**	**10,000**	**10,000**
Capital Equipment [b]	**21,560**	**27,790**	**40,250**
Startup [b]	**0**	**0**	**0**
Labor [b]	**7,600**	**12,200**	**22,000**
Consumables and Supplies [b]	**1,300**	**2,300**	**4,900**
Utilities [c]	**530**	**870**	**1,600**
Effluent Treatment and Disposal [c]	**0**	**0**	**0**
Residual and Waste Shipping and Handling [c]	**15,900**	**24,100**	**40,300**
Analytical Services [c]	**1,300**	**2,300**	**3,300**
Maintenance and Modifications [c]	**0**	**0**	**0**
Demobilization [b]	**1,000**	**1,000**	**1,000**
Total Fixed Costs 'a	$53,360	$6 1,090	$75,450
Total Variable Costs [b]	$26,630	$4 1,770	$72,100

Total Cost Per Cubic Yard Treated	$160	$103	$74

Notes:

[a] Costs are based on February 1993 dollars
[b] Fixed costs
[c] Variable costs

If paved storage areas need to be constructed (see Section 3.4.1, Site Preparation Costs) and if the treated soil requires disposal off site (see Section 3.4.9, Residual Waste Shipping and Handling), the total costs for treating 1,000 cubic yards of soil would increase by $220,000. This would increase the total cost per cubic yard treated to about $323.

3.2 Basis of Economic Analysis

BioGenesis claims that the **BioGenesis™** soil washing technology can be used to treat soils containing volatile, semivolatile, and nonvolatile organic compounds, petroleum hydrocarbons, chlorinated hydrocarbons, pesticides, and other organics. Soil contaminated with petroleum hydrocarbons was selected for this economic analysis because it is commonly found at Superfund and RCRA corrective action sites, it was encountered at both the Santa Maria and the oil refinery sites, and it involves most of the cost categories.

A number of factors affect the estimated costs of treating soil with the BioGenesis™ soil washing technology. These factors include type and concentration of contaminants, treatment goals, volume of contaminated soil, physical site conditions, geographical site location, site accessibility, and availability of utilities. Contaminant levels affect mixing time and the number of washes. Ultimately, the characteristics of residual wastes produced by the BioGenesis™ system affect disposal costs because they determine if the residuals require either further treatment or off-site disposal.

Cost data associated with the BioGenesis™ soil washing technology have been assigned to the following 12 categories: (1) site preparation; (2) permitting and regulatory requirements: (3) capital equipment; (4) startup; (5) labor; (6) consumables and supplies; (7) utilities; (8) effluent treatment and disposal; (9) residual waste shipping and handling; (10) analytical services; (11) maintenance and modifications; and (12) demobilization.

3.3 Issues and Assumptions

Based on operations at the refinery, the BioGenesis™ system will treat four 18-cubic-yard batches of soil per day for a total of 72 cubic yards per day. At this rate, the system would operate for 14 8-hour days to fully treat 1,000 cubic yards of soil contaminated with TRPH. Mobilization and demobilization activities would add an additional 2 days to the project, for an estimated total of 16 8-hour days to complete the project.

According to BioGenesis, the **BioGenesis™** cleaner stimulates microbial activity, which biodegrades residual soil and water contamination not removed by the process. This analysis assumes that no contamination will remain in the treated soil and that treated soils will be backfilled at the site. However, residual contamination could remain in the wastewater. Therefore, wastewater will require proper off-site disposal. If treated soils cannot be backfilled at a site, the costs per cubic yard of soil treated will be significantly higher.

BioGenesis' full-scale soil washing unit is currently available in one size only, and equipment operations are not complicated. Therefore, this analysis does not present equipment or operational cost alternatives.

Other assumptions used for this analysis include the following:

- The site is located near an urban area in the Midwest,
- Soil contamination at the site resulted from leaking underground storage tanks that contained diesel fuel.
- Access roads exist at the site.
- Adequate paved storage areas for treated and untreated soils exist at the site.
- Utility lines, such as electricity and telephone lines, exist on site.
- The soil to be treated contains 5,000 ppm TRPH,
- The treatment goal for the site will be to reduce the contaminant level to 2,000 ppm.
- No pretreatment of the feed soil will be required
- Soil will be treated in 18-cubic-yard batch cycles
- Treated soil will be backfilled at the site.
- Oversized materials constitute 2 percent of the feed soil and will be disposed of off site as petroleum-contaminated material.
- Recovered oil will be disposed of by an oil recycling company.
- 85 percent of the wash water will be recycled until the project is complete; wastewater will be stored and then disposed of off site; 15 percent of the wash water is lost due to soil retention and evaporation.

- The first batch will require 3,000 gallons of water; thereafter, each batch will require about 450 gallons of make-up water.

- BioGenesis will lease the treatment system, including labor and supplies, to its clients as part of an overall soil washing service.

- BioGenesis will provide two operators to operate all BioGenesis™ equipment; additional labor requirements include one site supervisor and one heavy equipment operator.

- Labor costs associated with major equipment repairs or replacement are not included.

3.4 Results

Results of the economic analysis are presented in this section. A hypothetical remediation site containing leaking underground storage tanks was assumed for this analysis.

3.4.1 Site Preparation Costs

Site preparation costs include administrative, security guard, and mobilization and electricity connection costs. This analysis assumes that leaking underground storage tanks have been removed from the site and that the area of contamination has already been delineated. Soil excavation will occur during treatment operations. This analysis also assumes a total of about 20,000 square feet will be needed to accommodate the BioGenesis™ unit, support equipment, and treated and untreated soil and water storage areas. Site preparation will take about 2 days to complete.

Site preparation costs are significantly affected by the availability of paved storage areas at a site. This analysis assumes adequate paved storage areas exist at the site and will require minimal modifications. Site preparation costs will increase by about $100,000, if a 1,000-square-foot concrete storage area needs to be constructed.

Administrative costs, such as legal searches, access rights, and other site planning activities, are estimated to be $10,000.

A security guard will be needed during evenings and weekends for the duration of the remediation project. In this analysis, the entire project will last about 16 days. During this time, the security guard will be needed for about 375 hours. At an hourly rate of $8.75, the total cost of security service will be about $3,300.

Mobilization involves transporting the entire **BioGenesis™** treatment system from Milwaukee, Wisconsin and delivering all rental equipment to the site. For this analysis, the site is located in the Midwest and equipment vendors are assumed to be situated nearby the site. The total estimated mobilization cost will be about $9,000.

3.4.2 Permitting and Regulatory Requirements

Permitting and regulatory costs will vary, depending on whether treatment is performed at a Superfund or a RCRA corrective action site and on how treated effluent and any solid wastes generated are disposed of. Superfund sites require remedial actions to be consistent with ARARs of environmental laws, ordinances, regulations, and statutes, including federal, state, and local standards and criteria. In general, ARARs must be determined on a site-specific basis. RCRA corrective action sites require additional monitoring records and sampling protocols, which can increase permitting and regulatory costs by an additional 5 percent.

For this analysis, permitting and regulatory costs include fees for highway permits for oversized vehicles and proof-of-process testing and reporting. Total permitting and regulatory costs for this analysis are estimated to be $10,000.

3.4.3 Capital Equipment

Capital equipment costs include leasing the complete BioGenesis™ treatment system, renting heavy equipment, obtaining a hot water service, renting one dumpster for storing oversized material, renting one portable toilet, and renting a wastewater holding tank.

The complete **BioGenesis™** treatment system includes the wash unit, the VOC emissions hood and carbon filter unit, all storage tanks, oil skimmers, strainers, transfer pumps, the API separator, the oil coalescer, and a flat bed trailer for ancillary equipment. The treatment system covers an area of about 1,200 square feet. BioGenesis personnel will operate the BioGenesis™ treatment system (see Section 3.4.5, Labor). BioGenesis will lease this equipment to its clients as the price for performing the soil washing service for a cost of about $10,000 to treat 1,000 cubic yards.

The heavy equipment that must be rented for excavating contaminated soil, loading contaminated soil into the wash unit, and transferring treated and untreated soils to storage areas includes a front-end loader, a backhoe, and a dumptruck. In addition, a forklift will be required for moving pallets of drummed waste and other materials. The front-end loader, backhoe, and dumptruck can be rented for about $2,400 per week. A forklift can be rented for about $500 per week. All the heavy equipment is assumed to be needed for the duration of the project, which for this analysis will be 16 days. Total heavy equipment costs will be about $9,000.

A hot water service will be needed because the **BioGenesis™** treatment system uses hot water. Complete hot water service including hot water truck, fuel, and operator is estimated to cost about $500 per day. This service will be required only during soil treatment activities, which for this analysis will be for 14 days. Total hot water service costs will be about $7,000.

Oversized material is assumed to constitute 2 percent of the feed soil. By this estimate, 1,000 cubic yards of soil will contain 20 cubic yards of oversized material. One 20-cubic-yard roll-off dumpster will be rented for storing oversized material. This analysis assumes the dumpster will be transported off site at the end of the project for disposing of oversized materials Dumpsters can be rented for about $200 per week, for a total cost of about $600.

Portable toilets can be rented for about $30 per week, for a total cost of about $90

A 5,000-gallon storage tank will be needed to store wastewater at the end of the project prior to approval for off-site disposal. It is assumed that this tank will be rented for three months at a cost of about $90 per week.

3.4.4 Startup

The costs of assembling the entire treatment system and initial startup activities are included in the price of retaining the soil washing service. BioGenesis will provide trained personnel to deliver, assemble, operate, and maintain the **BioGenesis™** treatment system. BioGenesis personnel are assumed to be trained in health and safety procedures. Therefore, training costs are not incurred as a direct startup cost. This analysis assumes that startup will take about 5 hours to complete.

3.4.5 Labor

BioGenesis will provide the personnel required to operate and maintain the **BioGenesis™** treatment system. The cost of these treatment system operators is included in the price of retaining the soil washing service. However, two heavy equipment operators and one site supervisor are also needed to complete the project. All staff are assumed to work 16 8-hour days to complete the project. All hourly labor wage rates presented in this analysis include overhead and fringe benefits. This analysis assumes personnel are already health and safety trained.

One heavy equipment operator will be needed to operate earth-moving equipment and the forklift, and one will be needed to operate the dumptruck. The labor wage rate for heavy equipment operators will be about $30 per hour, for a total of $7,700 (Means, 1993).

One site supervisor will be needed to oversee all operations, collect samples, and perform miscellaneous administrative functions. The labor wage rate for a site supervisor will be about $35 per hour, for a total of $4,500 (Means, 1993).

The total cost of labor for the duration of the project is estimated to be about $12,200.

3.4.6 Consumables and Supplies

Most consumables and supplies consumed during soil washing operations, including the **BioGenesis™** cleaner and antifoaming agents, are included in the price of retaining the soil washing service. The consumables and supplies costs applicable to this analysis include drums and disposable PPE.

Drums will be needed for storing recovered oil generated by the treatment system, sediments collected in the treatment system tanks, and disposable PPE. The generation rate of product oil and sediments will be site-specific. It was assumed that to treat 1,000 cubic yards of soil, about 50 55-gallon drums of oil and 40 55-gallon drums of sediment will be generated. Each drum costs about $14 each. Used PPE will be disposed of in 24-gallon fiber drums. This analysis assumes PPE will be changed for the duration of the project and fill about 12 drums. Fiber drums will cost about $12 each. Total drum costs are estimated to be about $1,500.

Disposable PPE includes Tyvek coveralls, gloves, booties, and air purifying respirator cartridges. Both treatment system operators will wear PPE during excavation or all of the time if necessary. The site supervisor will wear PPE during sample collection. The heavy equipment operators will not need to wear PPE unless working close to excavated soil. The treatment system operators will change PPE twice per day, costing about $50 per day. This analysis assumes PPE will be needed for the duration of the project. Total PPE costs are estimated to be about $800.

3.4.7 Utilities

Utilities used by the **BioGenesis™** treatment system and auxiliary equipment include water and diesel fuel. It should be noted that electricity may be used to operate the treatment system at some sites.

Soil washing requires about 3,000 gallons of water per load. About 85 percent of the wash water can be recycled and reused. This analysis assumes 15 percent of the total water requirements per batch, or about 450 gallons, will be lost due to soil retention and evaporation, requiring the same amount of makeup water. The total amount of water required to treat 1,000 cubic yards of soil over the duration of the project will be about 20,000 gallons. This analysis estimates water to cost $0.01 per gallon. Total water costs will be about $200. This cost can vary by as much as 100 percent depending on the geographic location of the site, availability of water, and distance to the nearest water main. Upon project completion, the remaining wash water will be placed in a storage tank prior to off-site disposal.

Diesel fuel will be used to power all heavy equipment used at the site. This analysis assumes 50 gallons per day will be required and that heavy equipment will be operated for the duration of the project. Total diesel fuel usage is estimated to be about 640 gallons. Diesel fuel is assumed to cost about $1.05 per gallon, for a total cost of about $670.

3.4.8 Effluent Treatment and Disposal

The only effluent produced by the **BioGenesis™** soil washing system that will require further processing prior to disposal is wastewater. The **BioGenesis™** cleaner transfers organic compounds from the soil matrix to the liquid phase. As such, the liquid phase will require treatment prior to discharging. This contaminated wastewater will be placed in a storage tank prior to approval for discharging to a POTW. The costs associated with disposal of wastewater are included in Section 3.4.9, Residual Waste Shipping and Handing. Cost of renting the 5,000-gallon storage tank is covered in Section 3.4.3, Capital Equipment.

3.4.9 **Residual Waste Shipping and Handling**

The residuals produced by the **BioGenesis™** soil washing system that will require off-site disposal include oversized materials, drummed sediments, drummed PPE, drummed recovered oil, and wastewater. If treated soils do not meet cleanup goals and require off-site disposal, the costs of disposal will be about $120 per cubic yard.

Oversized materials, which is expected to be nonhazardous, will be placed in a dumpster and disposed of off site at a landfill. For this analysis, about 20 cubic yards of material will need to be disposed of. Assuming disposal costs similar to those observed at the Santa Maria site, total oversized material disposal costs are estimated to be about $900.

Drummed sediments and drummed PPE will be disposed of off site at a landfill. For this analysis, about 50 drums will need to be disposed of. Based on observations made at the Santa Maria site, this analysis estimates transportation costs will be about $700 per trip, and disposal costs will be about $300 per drum. Disposing of these 50 drums is estimated to cost about $16,000.

Drummed recovered oil, if nonhazardous, will be disposed of by an oil recycling firm. For this analysis, about 2,700 gallons of recovered oil will need to be disposed of. Based on observations made at the SITE demonstrations, disposal costs will be about $0.45 per gallon. Total recovered oil disposal costs will be about $1,200.

Wastewater will be placed in a storage tank prior to approval by a wastewater disposal facility. For this analysis, about 3,000 gallons of water will need to be disposed of. Based on observations made during the SITE demonstration, disposal costs are estimated to be about $1.95 per gallon. Total wastewater disposal costs are estimated to be about $6,000.

3.4.10 Analytical Services

Analytical costs include laboratory analyses only. The costs of laboratory analyses include sample analysis, data reduction and tabulation, quality assurance/quality control (QA/QC), and reporting. This economic analysis assumes that the untreated soil at the site is well characterized. It is assumed that for treating 1,000 cubic yards of soil, 5 untreated soil samples and 20 treated soil samples will be collected to be analyzed for TRPH. This analysis will cost about $2,109. Data reduction, tabulation, QA/QC, and reporting are estimated to cost an additional $200. Total analytical costs are estimated to be about $2,300.

3.4.11 Maintenance and Modifications

BioGenesis™ treatment system equipment maintenance and modification costs are included in the price of retaining the soil washing service. Maintenance costs for all other equipment are assumed to be included in the cost of renting that equipment. Therefore, no maintenance or modification costs will be incurred.

3.4.12 Demobilization

Site demobilization costs will include decontamination and site restoration. This analysis assumes that shutdown, disassembly, and equipment return costs are included in the price of renting equipment and in retaining the soil washing service. All demobilization activities should be completed within 8 hours.

The BioGenesis™ treatment equipment, heavy equipment, paved storage areas, and tanks will all need to be decontaminated prior to demobilization. A power wash and steam cleaner can be rented for this activity for about $70 per day. Site restoration activities include regrading or filling excavation areas, and demolition and disposal of all fencing. Total demobilization costs are estimated to be about $1,000.

3.5 References

Evans, G., 1990, Estimating Innovative Technology Costs for the SITE Program. Journal of Air and Waste Management Association, 40:7, pages 1047 through 1051.

Means, 1993, Means Heavy Construction Cost Data, 1993, 7th Edition, Construction Publishers and Consultants, Kingston, Massachusetts.

SECTION 4

TREATMENT EFFECTIVENESS

Results of the SITE demonstration at the refinery site are presented in this section

4.1 Background

The refinery site is an active facility. The refinery contracted with BioGenesis to treat approximately 2,000 cubic yards of soil contaminated with crude oil. The contaminated soil was stored in a soil pile. BioGenesis collected one sample from the soil pile and analyzed it for TRPH and benzene, toluene, ethylbenzene, and xylenes (BTEX). Analysis revealed TRPH concentrations of 30,800 milligrams per kilogram (mg/kg), and BTEX concentrations of 0.24, 1.2, 0.25, and 4.3 mg/kg, respectively. Based on these results, TRPH was selected as the parameter of concern for the SITE demonstration.

The **BioGenesis™** technology was evaluated to determine its ability to extract TRPHs from soil. The objectives for the project were as follows:

* Determine removal efficiencies for TRPHs in the treatment system
* Evaluate whether or not the treatment system's performance is reproducible at constant operating conditions
* Gather information necessary to estimate treatment costs, including process chemical dosages and utility requirements
* Obtain information on biodegradation of TRPHs in treated soil by monitoring TRPH concentrations in the treated soil over a period of time

Three runs were conducted on three l8-cubic-yard batches of soil over 3 days. Soils from the pile were transported to the wash unit in a front-end loader with a bucket capacity of 4.5 cubic yards. Mixing time, BioGenesis™ cleaner concentration, and mixing intensity may influence the effectiveness of the soil washing process. BioGenesis determined the optimum values for these parameters during work at the refinery site prior to the SITE demonstration and kept them at constant during the demonstration. BioGenesis also raised the temperature of the wash water to 90°C using steam, believing that raising the temperature of the soil slurry during mixing would enhance contaminant transfer from soil to wastewater. Results of treatability studies conducted at

Santa Maria, California indicated that washing the soil slurry more than once increases the amount of contaminants transferred to wastewater. Therefore, BioGenesis washed each batch of soil twice with water.

4.2 Methodology

Because the **BioGenesis™** technology was developed to treat soils contaminated with organic compounds and because the principal contaminants in soil from the refinery are degraded petroleum hydrocarbons, TRPH was considered the critical analytical parameter. Samples for TRPH analysis were collected in triplicate from untreated and washed soils. For each bucket load in the front-end loader, 15 soil samples were collected and arranged in three sets. Therefore, for each run, 60 samples were arranged in three sets of 20 samples each. These 20 samples were homogenized, and a sample was collected from each set. Duplicate samples, if needed, were collected from the same set of homogenized samples. TRPH concentrations in treated and contaminated soils, water, and wastewater were monitored. Other parameters monitored included percent moisture in soils and sediment, metals concentration, pH, and total organic carbon (TOC) in selected soil samples; volume and density of untreated soils; and total suspended solids (TSS) in wastewater samples. Metals content was monitored to determine levels of metals that may be toxic to biodegrading microorganisms. Percent moisture, TOC, and pH were monitored to determine the physical and chemical characteristics of the soil that may affect treatment. The amount of solids transferred to the liquid phase was determined by monitoring TSS in wastewater.

Contaminated soil, prior to loading in the wash unit, was screened through a sieve with 4-inch-diameter mesh. Even after screening, soils contained large rocks and tar balls. The tar balls were hard and brittle and consisted primarily of soils with a core of tar-like material. The tar balls broke apart due to washing, and consequently, were rarely found in washed soil. Rocks and tar balls were not collected as samples since these were too large to introduce into the sample bottles. Questions arose regarding the homogeneity of the soils and representativeness of the sampling process. To address this issue, 346 kg of soil was screened through a 0.5-inch-diameter screen during Run 1. Rocks and tar balls remaining on the screen were separated by hand and weighed. The rocks and tar balls weighed 31 kg and 9.15 kg, respectively. Two rock samples and two tar ball samples were collected and analyzed in triplicate for TRPH. The data are presented in Table 4-l. As expected, TRPH concentrations in rocks were approximately two orders of magnitude lower than those in the tar balls. TRPH concentrations in the rock samples varied

Table 4-l. Total Recoverable Petroleum Hydrocarbon Concentrations in Rocks and Tar balls, mg/kg

	Sample 1	Duplicate 1	Triplicate 1	Sample 2	Duplicate 2	Triplicate 2
Rocks	520	330	290	280	53	54
Tar balls	25,000	29,000	22,000	15,000	16,000	10,000

approximately one order of magnitude, reflecting the difficulty in homogenizing such samples. Average concentrations of rocks and tar balls were 254 mg/kg and 19,500 mg/kg, respectively. Calculations were made to estimate the error introduced by not accounting for the rocks and tar balls during soil sampling. The mass of TRPH associated with rocks is equal to the average TRPH concentration in rocks multiplied by the mass of the rocks:

254 mg/kg x 31 kg = 7,874 mg

Similarly, the mass of TRPH associated with tar balls was calculated as follows:

19,500 mg/kg x 9.15 kg = 78,425 mg

Out of the 346 kg of soil screened through the 0.5-inch-diameter screen, 305.85 kg contained an average TRPH concentration of 7,666 mg/kg (average of TRPH values in contaminated soil during Run 1). Therefore, the mass of TRPH associated with screened soil was calculated as follows:

7,666 mg/kg x 305.85 kg = 2,344,646 mg

The mass of TRPH associated with rocks, tar balls, and screened soil was then summed to calculate the total mass of TRPH in screened soil:

7,874 mg + 178,425 mg + 2,344,646 mg = 2,530,945 mg

Without the rocks and the tar balls, mass of TRPH in the same amount of soil is as follows:

$$7{,}666 \text{ mg/kg} \times 346 \text{ kg} = 2{,}652{,}436 \text{ mg}$$

Therefore, error introduced due to not accounting for the rocks and tar balls was calculated as follows:

$$(2{,}652{,}436 \text{ mg}/2{,}530{,}945 \text{ mg}) \times 100 - 100 \text{ percent} = 4.8 \text{ percent}$$

Therefore, the presence of rocks and tar balls in soils causes TRPH concentrations to be overestimated by an insignificant amount. Based on this result, the presence of rocks and tar balls in soil, and the failure to account for this in the sampling process, is not expected to affect the TRPH data obtained during the demonstration.

4.3. Physical Analyses

Three contaminated soil samples were collected during the demonstration to determine soil density. A metal cubitainer with a volume of 1 cubic foot was filled with soils and weighed. The average density of the soil was determined as 1.74 grams per cubic centimeter. Based on 18 cubic yards (14.14 cubic meters) of soil, the mass of soil treated during each run was 24.6 metric tons.

The volume of wash water was monitored during each run. Data are presented in Table 4-2. BioGenesis determined the amount of water to be used during each wash and used about 23 liters of **BioGenesis™** cleaner during each wash. Therefore, although cleaning solution concentrations during each wash varied, BioGenesis determined this operating condition to be optimum.

Table 4-2. Volume of Water **Used For Washing**

Run Number	Wash Number	Volume (Liters)
1	1	17,080
	2	14,340
2	1	16,280
	2	11,750
3	1	12,810
	2	17,870

Particle size distribution (PSD) of soils is another characteristic that may influence contaminant transfer from soils to water. The PSD data for soils used during the three runs are presented in Table 4-3. Soils at the refinery had a PSD averaging 13% gravel, 76% sand, 6% silt and 5% clay. About 89% of the soils were sand or coarser grained particles. Soil washing processes, in general, are more effective with coarse grained soils.

Table 4-3. Particle Size Distribution of Untreated Soils, in percent

Run	**Gravel** Particle Diameter > 4.75 mm	**Sand** Particle Diameter 0.075 - 4.75 mm	**Silt** Particle Diameter 0.005 - 0.075 mm	**Clay** Particle Diameter < 0.005 mm
1	10.3	78.2	6.8	4.7
1 (duplicate)	11.5	76.7	7.9	3.9
2	13.9	73.9	6.4	5.8
3	13.8	76.5	4.3	5.4

4.4 Chemical Analyses

Analytical results for untreated and treated soils from Runs 1, 2, and 3 are presented in Tables 4-4, 4-5, and 4-6, respectively. The metals concentration data show that metals were present at levels generally found in natural soils and were not expected to be toxic to biodegrading microorganisms. Metals concentrations in the treated and untreated soils did not, and were not expected to, reflect any discernible effect of the soil washing because metals were not targeted with a metal washing surfactant blend. TOC and pH, which were analyzed for untreated soil only, showed comparable values between runs. Sorption and desorption characteristics of organics from soils are influenced by TOC content of the soil. TOC was monitored to determine its impact on contaminant transfer. TOC values ranged from 1.6 percent to 1.8 percent. These TOC values were comparable to values generally found in surface soils and indicate that petroleum hydrocarbons would strongly sorb onto the soil. Since the **BioGenesis™** cleaner is alkaline, acidic soil may decrease efficiency of contaminant transfer. The pH of untreated soils was near neutral levels and was not expected to affect the treatment process.

Table 4-4. Analytical Results from Run 1 of the BioGenesis SITE Demonstration, mg/kg solids, dry weight

Parameter	Untreated Soil				Treated Soil			
	Sample 1	Field Duplicate 1	Sample 2	Sample 3	Sample 1	Field Duplicate 1	Sample 2	Sample 3
TRPH	8,300	7,500	7,600	7,500	2,900	3,000	2,400	2,600
Percent Moisture	8.6	7.5	8.6	7.6	6.1	4.8	7.1	7.1
Arsenic	2.8	2.2	NA*	NA	1.8	2	2.5	NA
Barium	36	19	NA	NA	19	16	36.3	NA
Cadmium	0.39†	<.37	NA	NA	<0.36	<0.37	<0.37	NA
Chromium	13	7.7	NA	NA	9.4	10.3	15	NA
Copper	8.7	5.8†	NA	NA	9.1	7.7	9.5	NA
Lead	10	4.5	NA	NA	5.6	3.8	9.4	NA
Mercury	0.05†	0.05†	NA	NA	0.06†	0.04†	0.05†	NA
Nickel	12	7.9	NA	NA	9.1	7[a]	13	NA
Selenium	0.48	<.38	NA	NA	<0.36	<0.37	<0.36	NA
Silver	<0.75	<0.75	NA	NA	<.72	<0.74	<0.75	NA
Sodium	160	130†	NA	NA	120†	98†	150†	NA
Zinc	26	13	NA	NA	35	18	26	NA
pH (pH units)	8.1	8.2	NA	NA	NA	NA	NA	NA
TOC	16,000‡	16,000‡	NA	NA	NA	NA	NA	NA

Notes:

* Not analyzed.
† Less than five times detection limit.
‡ Average of TOC and TOC analytical duplicate values.

Table 4-5. Analytical Results from Run 2 of the BioCenesis SITE Demonstration, mg/kg solids, dry weight

Parameter	Untreated Soil			Treated Soil		
	Sample 1	Sample 2	Sample 3	Sample I	Sample 2	Sample 3
TRPH	7,700	7,900	7,100	2,100	2,000	2,000
Percent Moisture	IO	10	11	6.3	8.4	7.9
Arsenic	2.9	NA*	NA	2.8	NA	NA
Barium	33	NA	NA	I4	NA	NA
Cadmium	0.39	NA	NA	<0.38	NA	NA
Chromium	13	NA	NA	I4	NA	NA
Copper	9.8	NA	NA	6.3+	NA	NA
Lead	9.7	NA	NA	4.5	NA	NA
Mercury	<0.048	NA	NA	<0.042	NA	NA
Nickel	I3	NA	NA	I2	NA	NA
Selenium	0.38	NA	NA	<0.38	NA	NA
Silver	<0.78	NA	NA	<.77	NA	NA
Sodium	23	A	NA	130†	NA	NA
Zinc	26	NA	NA	16	NA	NA
pH (pH units)	7.8	NA	NA	NA	NA	NA
TOC	16,600#	NA	NA	NA	NA	NA

Notes:

* Not analyzed.
\+ Less than five times detection limit.
\# Average of TOC and TOC analytical duplicate values.

Table 4-6. Analytical Results from Run 3 of the BioGenesis SITE Demonstration, mg/kg solids, dry weight

Parameter	Untreated Soil			Treated Soil		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
TRPH	8,800	10,000	11,000	2,700	2,900	2,900
Percent Moisture	9.8	8.0	8.5	7.1	6.9	8.7
Arsenic	3.6	NA*	NA	NA	NA	NA
Barium	30	NA	NA	NA	NA	NA
Cadmium	<0.37	NA	NA	NA	NA	NA
Chromium	13	NA	NA	NA	NA	NA
Copper	11	NA	NA	NA	NA	NA
Lead	I1	NA	NA	NA	NA	NA
Mercury	<0.047	NA	NA	NA	NA	NA
Nickel	11	NA	NA	NA	NA	NA
Selenium	0.66+	NA	NA	NA	NA	NA
Silver	<0.75	NA	NA	NA	NA	NA
Sodium	110+	NA	NA	NA	NA	NA
Zinc	26	NA	NA	NA	NA	NA
pH (pH units)	7.8	NA	NA	NA	NA	NA
TOC	18,000‡	NA	NA	NA	NA	NA

Notes:

- * Not analyzed.
- † Less than five times detection limit.
- ‡ Average of TOC and TOC analytical duplicate values.

TRPH data in Tables 4-4, 4-5, and 4-6 show that replicate samples produced comparable results. Average TRPH concentrations in treated and untreated soils are summarized in Table 4-7. Table 4-7 shows that TRPH removal during Runs 1,2, and 3 was 65, 73, and 72 percent, respectively indicating that the **BioGenesis™** treatment system's performance is reproducible at constant operating conditions.

Table 4-7. Average TRPH Concentrations in Untreated and Washed Soils, mg/kg

Run Number	Untreated Soil	Treated Soil	Percent Removal
1	7,666	2,650	65
2	7,567	2,033	73
3	9,933	2,833	72

The **BioGenesis™** treatment system also enhances biodegradation in treated soil. The SITE demonstration was conducted in November when temperature at the site was near 30°F. Since the temperature at the site was expected to be near or below freezing, biodegradation of contaminants in the treated soil pile at the site was expected to proceed slowly. Therefore, the biodegradation study was conducted in a laboratory. Treated soils from Runs 2 and 3 were collected in 5-gallon buckets and stored at 70°F in a laboratory for monitoring over a period of time. BioGenesis added additional surfactant solution to the buckets at the time of collection. Samples *were* collected on Day 14, Day 40, Day 60, Day 90, Day 120, and Day 180 after treatment to determine the extent of biodegradation in treated soil. Samples for analyses were collected by homogenizing three to seven grab samples from each bucket. Duplicate samples were collected from the same batch of homogenized samples. Results of TRPH analyses are presented in Table 4-8. Average TRPH concentrations in these samples are plotted in Figure 4- 1. Table 4-8 and Figure 4- 1 indicate that TRPH concentrations continued to decrease up to I20 days. Further reduction in TRPH levels was not observed after 120 days. BioGenesis added additional surfactant solutions to the treated soil on-site between Day 120 and Day 150. Subsequently, the refinery transferred the soils to another location and added contaminated soil to the treated soil pile. Therefore, it is highly unlikely that representative treated soil samples could be obtained to verify the results of the laboratory biodegradation study. For soils collected for the biodegradation study, additional surfactant solution was added only at the beginning of the study. Biogenesis believes that during the laboratory biodegradation study, biodegradation was inhibited between Days 120 and 180

Table 4-8. TRPH Concentrations in Treated Soil, mg/kg

Run/Day	Sample 1	Sample 2	Sample 3
Run 2			
Day 0	2,100	2,000	2,000
Day 14	2,200	2,100	2,600
Day 40	2,000	2,000	2,000
Day 60	1,600	NA*	NA
Day 90	1,100	970	1,000
Day 120	980	920	970
Day 180	1,060	1,100	1,000
Run 3			
Day 0	2,700	2,900	2,900
Day 14	3,100	3,200	2,900
Day 40	2,600	3,300	2,700
Day 60	2,100	NA	NA
Day 90	1,500	1,400	2,300
Day 120	1,200	1,100	1,000
Day 180	1,380	1,590	1,390

Note:

* Not available.

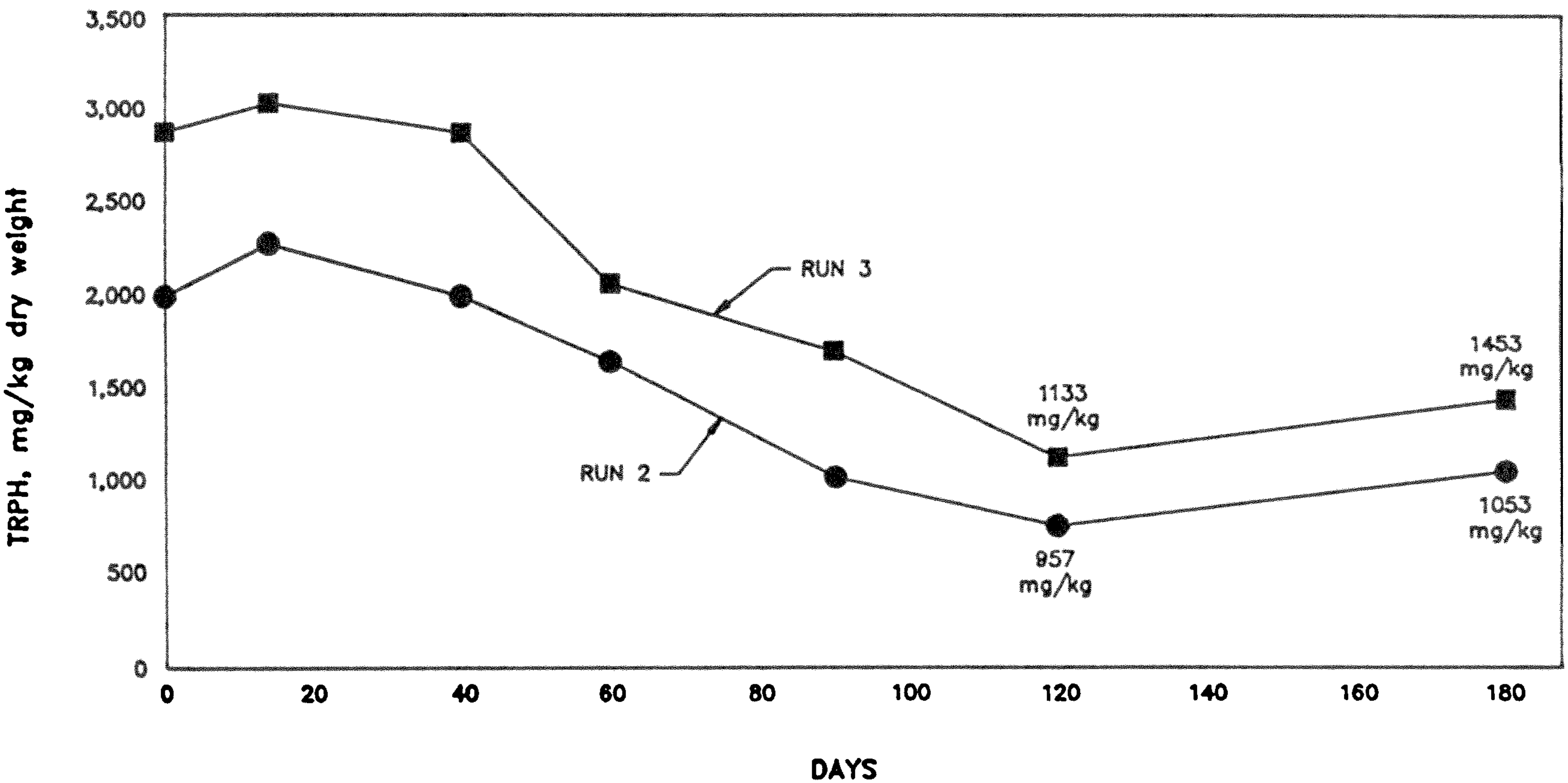


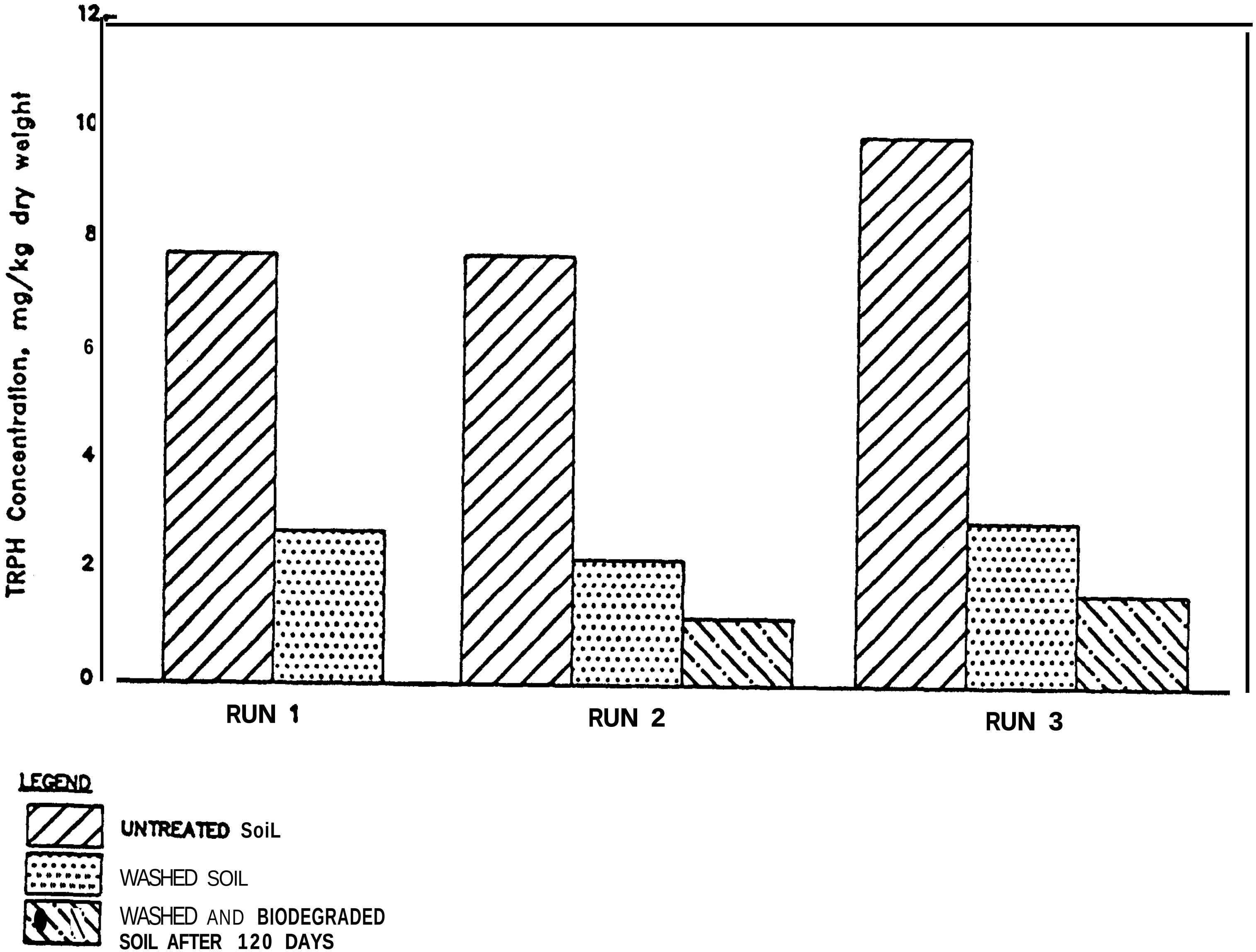
Figure 4-1. Biodegradation results; TRPH concentrations from treated soils over tim

due to nutrient limitations, The microorganisms apparently required an acclimatization period of about 40 days.

Results of TRPH concentrations in untreated soils after washing from Run 1 and following washing and biodegradation up to 120 days from Runs 2 and 3 are plotted in Figure 4-2. Soils from Runs 2 and 3 show a removal efficiency of 83 and 88 percent, respectively, from washing and biodegradation.

To confirm that a healthy population of microorganisms capable of degrading crude oil was present in the treated soil, samples collected on Day 90 were characterized for bacterial population. Samples were analyzed to determine the population of aerobic heterotrophic bacteria that require organic compounds for growth and reproduction. The population of aerobic heterotrophic bacteria in these samples ranged between 7.3 x 10^7 colony forming units per gram (CFU/gm) to 1.3 x 10^8 CFU/gm. Petroleum aerobic hydrocarbon-utilizing bacteria, a subset of heterotrophic bacteria, that can degrade petroleum hydrocarbons were also analyzed. The population of hydrocarbon utilizing bacteria in these samples ranged between 5.7 x 10^6 CFU/gm to 1.1 x 10^7 CFU/gm. In general, there were no major differences in the colony appearance or morphology in the soil samples. The same types of organisms were present in each sample. The numbers of different types of colonies, or colony diversity, was high. This indicates the population was healthy and not dependent on one dominant organism. A well established population is flexible and can easily reestablish its numbers when assaulted by pH shifts, temperature shifts, or chemical additions. It also indicates that the surfactant, the defoaming agent, and the degradation products of petroleum hydrocarbons are not toxic to the microorganisms. In summary, the bacterial analysis indicated the presence of a healthy and diverse bacterial population well acclimated to hydrocarbons as a carbon source in the treated soil,

Although wastewater samples were collected during the demonstration, some of the wastewater was discharged directly into the drains leading to the refinery's wastewater treatment system. During each wash, wastewater samples were collected twice: once from wastewater skims containing mostly oily materials and again from wastewater drained at the end of the wash. The TRPH and TSS data are presented in Table 4-9. TRPH and TSS values in the wastewater skims for all runs ranged from 76 to 1,500 milligrams per liter (mg/L) and 10,000 to 83,000 mg/L, respectively. TRPH and TSS in wastewater at the end of the wash ranged from 95 to 700 mg/L and 4,200 to 23,000 mg/L, respectively. The TSS data indicated that large amounts of fine



Rigure 4-2. Average TRPH concentrations In treated and untreated soils. Bfodegradatfon study only conducted during runs 2 and 3.

Table 4-9. TRPH and TSS in Wastewater, mg/L

Run Number	Wash Number	Wastewater Skims		Drained Wastewater	
		TRPH	TSS	TRPH	TSS
1	1	680[a]	46,000[a]	95	12,000
	2	195	10,000	170[a]	4,200[a]
2	1	470	82,000	360	18,000
	2	76	31,000	700	6,900
3	1	1,200	83,000	140	23,000
	2	1,500	32,000	180	9,000

Note:

Average of duplicate field samples

particles were present in the wastewater. A mass balance of TRPH in the system was not possible because data regarding volume of wastewater was unavailable.

TRPH concentrations in washwater, BioGenesis™ cleaner, and a defoaming agent used by BioGenesis were monitored. TRPH concentrations in these media were either at low levels or below detection limits and were not expected to impact TRPH levels in soils or wastewater.

Information available prior to the SITE demonstration indicated that volatile compounds, including chlorinated solvents, were present only at trace levels in contaminated soil. In addition to TRPH and metals, soils and tar balls collected during Run 3 were also analyzed for BTEX and total petroleum hydrocarbon as gasoline (TPH-gasoline). Results of the chemical analyses are presented in Table 4-10. The data show that concentrations of volatile compounds, except toluene, decreased by approximately an order of magnitude in the washed soil compared to the untreated soil. However, the decrease is attributable to both losses due to volatilization during soil washing and contaminant transfer from soil to water. Concentrations of volatile organics were found to be lower in the tar ball samples compared to untreated soils.

Table 4-10. Selected Volatile Organics in Contaminated Soil, (micrograms/kilogram)

Chemical	Untreated Soil			Treated Soil			Tar Balls	
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2
Benzene	<320	<160	<160	40[C]	41[C]	36[C]@	<67	62[C]
Ethylbenzene	950[C]	630[C]	740[G]@	97[C]	90[C]	100[C]@	460[G]	250[C]
Gasoline	1,100,000[G]	820,000[G]	870,000[G]	160,000[G]	160,000[G]	150,000[G]	510,000[G]	230,000[G]
Toluene	630[C]	660[C]	540[C]@	230[C]	230[C]	240[C]	120[G]	360[C]
Xylenes	5,200’	3,500[C]	4,600’	620[C]	260[C]	590[C]	3,900[G]	1,200[C]

Notes:

@ Less than five times detection limit

G For gasoline indicates an estimated value since the pattern does not exactly match the standard profile. For toluene and ethylbenzene indicate that the first and second column concentrations differ by more than two times.

C This analysis was confirmed on a second column or by gas chromatography/ mass spectroscopy.

Treated soils from Runs 2 and 3 were collected on Day 180 and analyzed for selected volatile organics. The results are presented in Table 4-l1. Toluene and xylenes were the only volatile compounds detected in these samples. Reductions in levels of volatile compounds in these samples are expected primarily due to volatilization. Comparing volatile organic concentrations from Tables 4-10 and 4-l1, losses due to volatilization in 180 days can be conservatively estimated at approximately 160 mg/kg. Table 4-8 shows that during the biodegradation study, TRPH levels were reduced approximately between 1,000 and 1,700 mg/kg. Furthermore, volatile components present in soils are not expected to be accounted for in the TRPH data, since the sample preparation method for TRPH analysis is expected to drive off volatile components. Leaching is not expected to contribute to TRPH reduction, since the soils were contained in buckets. Therefore, reductions in TRPH levels observed during the biodegradation study are attributable to processes other than losses due to volatilization and leaching, such as biodegradation.

4.5 Residuals

Residual wastes from the **BioGenesis™** treatment system include both liquid and solid wastes. Operation of the **BioGenesis™** treatment system generates the following wastes:

- Treated soils will be placed in on-site roll-off bins and covered with plastic sheeting until analytical results are received. Treated soils may require further treatment or disposal at permitted facilities.
- Wastewater generated during the process and decontamination water will usually require further treatment at permitted wastewater treatment facilities. For most sites, BioGenesis proposes to recycle wastewater and finally treat it with its oil/water separators and bioreactor. Wastewater may also be disposed of in underground injection wells.
- Suspended soil particles will be recovered directly from spent wastewater; if these sediments are present in appreciable amounts, they will require further treatment.
- Recovered oil or hydrocarbons will be collected in 55-gallon drums and temporarily stored on site; management or disposal requirements will be determined after analytical results are received.
- If volatile emissions are released during the soil washing process, used carbon filters from the wash unit hood will be properly disposed of off site
- Disposable personal protection equipment (PPE) will be stored in 55-gallon drums and transported off site for incineration or landfill disposal.

Table 4-11, Selected Volatile Organics in Treated Soil, Day 180, micrograms/kilogram dry weight

Contaminant	Run 2			Run 3		
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
Benzene	<31.8	<31.8	<31.8	<32.2	<32.6	<32.7
Ethylbenzene	**32.6**[K]	<31.8	<31.8	<32.2	<32.6	<32.7
Gasoline	<5,290	<5,300	<5,290	<5,450	<5,520	<5,530
Toluene	**50.7**[c]	**55.1**[c]	**51.2**[c]	39.2’	**39.4**[c]	**40.9**[c]
Xylenes	**120**[c]	**109**[c]	**112**[c]	**96.1**[c]	96.2’	**99.7**[c]

Notes:

[c] Confirmed by second column analysis.

[K] Primary column peak at this retention time did not meet method identification criteria. Analyte not detected on second GC column.

After washing and biodegradation, treated solids may require disposal at permitted facilities. Contaminated soil at the refinery was not hazardous, as defined by RCRA or state regulations. TRPHs in the treated soils from the refinery will be allowed to biodegrade before disposal. Soils at the refinery are being stored in a large pile. BioGenesis expects that the TRPH in the soil will eventually decrease to levels that will meet local regulatory requirements for reuse of the soil as fill material. Wastewater will usually require further treatment. For most sites, BioGenesis proposes to recycle wastewater and finally treat it with its oil/water separators and the bioreactor. However, such equipment was not used at the refinery. Sediments in the wastewater, if present at appreciable amounts, require further treatment. BioGenesis™' wash unit is equipped with carbon filters to treat volatile emissions. However, because volatile compounds were not present in soils treated at the refinery, the carbon filters were not used.

Assuming that the treated soil will meet regulatory requirements for reuse as fill material, wastewater and sediments in wastewater were the only residuals generated at the refinery. It was not possible to measure the volume of wastewater at the refinery. Assuming that volume of wastewater is the same as the volume of water used for washing, approximately 15,000 liters (average volume of water used during the three runs) of wastewater was generated to treat 18 cubic yards of soil. Estimation of amount of sediment in wastewater is complicated by the fact that the amount of wastewater withdrawn from the wash unit during skimming as compared to during draining at the end of the wash is not known.

TRPH concentrations in wastewater range from 76 to 1,500 mg/L. Disposal methods for wastewater include further treatment and injection in underground wells. TRPH in sediment is expected to be high and would require further treatment prior to disposal.

SECTION 5
OTHER TECHNOLOGY REQUIREMENTS

5.1 Environmental Regulation Requirements

State regulatory agencies may require permits to be obtained prior to implementing the BioGenesis™ treatment system. A permit may be required to operate the system. An air emissions permit and a permit to store contaminated soil in drums on site for greater than 90 days may also be required. A permit is also needed for storage in a waste pile for any length of time.

If off-site disposal of contaminated soils is required, soils must be taken off site by a licensed transporter to a permitted landfill. Wastewater generated by the BioGenesis™ treatment system must be discharged to a permitted wastewater treatment plant or disposed of in a permitted underground injection well.

6.2 Personnel Issues

Two technicians are required to operate the BioGenesis™ treatment system. In addition, one BioGenesis employee familiar with the wash unit's performance will be needed to determine the optimum operating conditions specific to each site. The efficiency of the wash unit is affected by soil and contaminant types. If soil excavation is required, additional personnel will be needed to operate earth-moving equipment. The BioGenesis™ treatment system should be operated during daylight hours unless sufficient flood lights are available to operate the system after dark.

For most sites, PPE for workers will include gloves and overalls. Depending on contaminant types and concentrations, additional PPE may be required. Noise levels should be monitored to ensure that workers are not exposed to noise levels above a time-weighted average of 85 decibels, over an 8-hour day. If operation of the BioGenesis™ treatment system increases noise levels above this limit, workers will be required to wear additional protection.

5.3 Community Acceptance

Potential hazards related to the community include exposure to volatile pollutants and other particulate matters released to air during soil excavation and handling. Further, the biodegradation process may require contaminated soils to remain stockpiled on site for extended periods of time. This could expose the community to airborne emissions for several months. Air emissions can be managed by watering down the soils prior to excavation and handling and covering the stockpiled soil with plastic.

If volatile compounds are present in contaminated soils, operation of the wash unit may release volatile emissions. The **BioGenesis™** wash unit is equipped with carbon filters to treat volatile emissions.

SECTION 6
TECHNOLOGY STATUS

BioGenesis treated 2,000 cubic yards of crude oil-contaminated soil at the refinery site. In addition to samples collected during the SITE demonstration, three untreated soil samples were collected by BioGenesis. BioGenesis presents the results of chemical analyses and its interpretation of the data in Appendix I.

The **BioGenesis™** technology was used to treat contaminated harbor sediments in Thunder Bay, Ontario, Canada, in June 1993. BioGenesis presents the treatment results in Appendix II.

APPENDIX I

BIOGENESIS ENTERPRISES, INC.
SUPPLEMENTARY DATA FOR UNTREATED SOIL. TRPH LEVELS

BioGenesis Enterprises, Inc. (BioGenesis), reports that untreated soil samples tested for the refinery and samples tested for BioGenesis by an independent laboratory all contained TRPH levels significantly higher than in the samples collected during the SITE demonstration. Test results, their source, and sampling dates are as follows:

Date	Tested By	Test Method	Before Washing TRPH (ppm)
April 1992	Refinery's Independent Lab	418.1 (IR)	**40,148**
July 1992	Refinery's Independent Lab	**418.1** (IR)	16,500
October 1992	BioGenesis' Independent Lab	9073 (GC)	30,800

These results differ significantly from the untreated soil range of TRPH of 7,700 to 11,000 parts per million (ppm) observed during the demonstration. Differences are attributable partly to degradation of oil in the soil and to differences in sampling and sample handling. BioGenesis recommends that process efficiency be viewed as the result of washing combined with biodegradation. The impact of the different results on washing efficiency is shown in the following tables. These results are based on TRPH data for Runs 2 and 3 of the demonstration and degradation to 120 days as documented in this report.

Tested By	Average Calculated Wash Efficiency (Biodegradation Excluded)	Average Calculated Process Efficiency (Biodegradation Included)
Refinery, 4/92	94%	95%
Refinery, 7/92	85%	85%
BioGenesis, 10/92	88%	97%
Demonstration, 11/92	72%	88%

APPENDIX II

BIOGENESIS ENTERPRISES, INC.
SUPPLEMENTARY DATA ABOUT WASHING EXTREMELY FINE SEDIMENTS FROM A FORMER WOOD TREATING SITE

In addition to SITE program testing, BioGenesis has developed a method of cleaning oils, organic chemicals, PCBs, and heavy metals from very fine sediments with particles less than 50 microns in size. Numerous harbors and rivers have large volumes of sediments with high contamination levels from wood preserving, dumping, and other chemical processes. In addition, this method has significant applications in the oil industry for treating drilling mud containing fines.

To date, soil washing using particle segregation/classification and washing techniques borrowed from the mining industry have successfully cleaned coarse particles but have been unable to clean the fines. The ex-mining technology has been well developed in Europe and is being imported to the U.S. EPA reviewed this technology in 1990 and concluded it should be viewed principally as a volume reduction method that concentrates the pollutant to about 30 percent of the original volume.

In December 1992, Wastewater Technology Centre (WTC), the Canadian EPA's test and development organization, contracted with BioGenesis to test BioGenesis sediment washing. The testing was conducted under the Great Lakes Cleanup program and involved cleaning contaminated sediment from a wood treating site at Thunder Bay Harbour, Ontario. The principal contaminant is polycyclic aromatic hydrocarbons (PAHs). Sieve testing showed that 80 percent of the sediment is smaller than 38 microns in size.

In June 1993, with the participation of WTC representatives, Thunder Bay sediment was processed through a field prototype machine using the BioGenesis process at a rate of 2 cubic yards per hour. Results are summarized in the following tables. Results are for initial washing and do not include the effect of residual biodegradation.

Test Parameter	Before Washing (ppm)	After Washing (ppm)	Removal Percent
Total Petroleum Hydrocarbons	4,770	400	91.6
Oil and Grease	91,600	3,940	95.7
Semivolatile Petroleum HC (C12-C23 as diesel)	21,000	2,200	89.5
Total Organic Carbon	11.5%	2.9%	74.8

Polyaromatic Hydrocarbons (PAHs)	CAS	Before Washing ppm	After Washing ppm	Removal Percent
Naphthalene	**91-20-3**	**1,400**	**73**	**94.8**
Acenaphthylene	**208-96-8**	**16**	**1.5**	**90.6**
Acenaphthene	**83-32-9**	**305**	**34**	**88.9**
Fluorene	**86-73-7**	**240**	**30**	**87.5**
Phenanthrene	**85-01-8**	**770**	**88**	**88.6**
Anthracene	**120-12-7**	**110**	**16**	**85.5**
Fluoranthene	**206-44-0**	**400**	**59**	**85.3**
Pyrene	**129-00-0**	**300**	**44**	**85.3**
Benzo(a)anthracene	**56-55-3**	**115**	**19**	**83.5**
Chrysene	218-01-9	75	12	84.0
Benzo(b)fluoranthene	205-99-2	120	19	84.2
Benzo(k)fluoranthene	207-08-9	42	6.10	85.5
Benzo(a)pyrene	50-32-S	82	12	85.4
Indeno(l,2,3-cd)pyrene	193-39-5	30	5	83.3
Dibenzo(a,h)anthracene	53-70-3	8.90	1.40	84.3
Benzo(g,h,i)perylene	19 l-24-2	28	3.90	86.1
		4,041.90	423.90	89.5

Notes:

1 Five minute wash cycle utilized with continuous process washing system.

2 Washing audited by Wastewater Technology Centre (Canadian EPA). Independent testing by Galson Laboratories, Syracuse, New York.

3 Detailed test reports available from BioGenesis.