NAVAL FACILITIES ENGINEERING SERVICE CENTER
Port Hueneme, California 93043-4301

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BIOPILE DESIGN AND CONSTRUCTION MANUAL

by

BATTELLE
Columbus, Ohio 43201-5263

and

NFESC
Port Hueneme, California 93043-4301

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Prepared for

Naval Facilities Engineering Service Center
Port Hueneme, California

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Prepared by

BATTELLE
Environmental Restoration Department
505 King Avenue
Columbus, Ohio 43201

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ABSTRACT

This manual was created to support biopile work being conducted at U.S. Navy and Marine Corps facilities. This document details the selection procedures and design and construction steps for implementing the biopile technology, which is a method for ex situ treatment of soils contaminated with petroleum hydrocarbons. The manual provides a general overview of the biopile technology, followed by detailed descriptions of selection criteria, regulatory issues, design parameters, and construction procedures. Depending on factors such as volume of soil to be treated, material handling, and the available area to construct the biopile, one may choose to construct a single cell or a number of similar cells (modular approach). For the purpose of consistency and to facilitate numerous calculations, a baseline 500-yd^3 (382-m^3) treatment cell is considered in this manual. Two designs are presented for the baseline pile size of 500 yd^3 (382 m^3): one for a temporary system, and one for a permanent system.

The scope of this document is to present the design and construction procedures for a biopile. A companion document titled *Biopile Operations and Maintenance Manual* (TM-2190-ENV) provides detailed procedures for biopile system operations (e.g., sampling) and maintenance, and information to decide when to terminate the system operation. The document is composed of a main body and a series of appendices containing relevant technical and support details.

BIOPILE DESIGN AND CONSTRUCTION MANUAL

Section 1.0: INTRODUCTION

1.1 Background and Objectives. A large number of U.S. Department of Defense (DoD) sites reportedly have petroleum- and fuel-contaminated soils and groundwater as a result of leaking underground storage tanks (USTs) and pipelines or other accidental releases. With so many sites requiring remediation at relatively high costs, the Naval Facilities Engineering Service Center (NFESC) has been developing and demonstrating more effective and less costly remedial alternatives. The NFESC has successfully demonstrated the applicability of biopiles to reduce the concentration of petroleum constituents in excavated soils through the use of aerobic biodegradation. The purpose of this manual is to provide design features for a biopile; a companion document titled *Biopile Operations and Maintenance Manual* (NFESC, 1996, TM-2190-ENV) presents operations and maintenance procedures for a biopile.

1.2 Overview. Biopile technology involves forming petroleum-contaminated soils into piles or cells above ground and stimulating aerobic microbial activity within the soils through aeration. Microbial activity can be enhanced by adding moisture and nutrients such as nitrogen and phosphorus. The aerobic microbial activity degrades the petroleum-based constituents adsorbed to soil particles, thus reducing the concentrations of these contaminants. Biopiles typically are constructed on an impermeable base to reduce the potential migration of leachate to the subsurface environment. A perforated piping network installed above the base is connected to a blower that facilitates the aeration of the pile. In some cases, a leachate collection system is constructed, especially if a moisture addition system is being considered for the pile. The piles generally are covered with an impermeable membrane to prevent the release of contaminants and/or contaminated soil to the environment and to protect the soil from wind and precipitation. Biopiles operate effectively in temperate climates but can be operated in colder climates by introducing warm air through the aeration process.

The advantages of the biopile technology include the following:

- The contaminants are destroyed, making this a toxicity reduction process that is preferred by the regulators.
- Biopile systems are relatively easy to design and construct.
- Remediation can be completed in a relatively short time (3 to 6 months). Future containment of the treated soil is not required.
- Biopiles offer a cost-competitive technology compared to thermal desorption, which is another commonly used aboveground treatment technology.
- Biopiles can be cost-competitive with landfilling and are preferred over landfilling.
- Biopile technology is effective on organic contaminants that are difficult to desorb.
- Biopiles can be engineered to be potentially effective for any combination of site conditions and petroleum products.

The biopile technology has the following limitations:

- Biopiles may not be effective for high contaminant concentrations (>50,000 ppm total petroleum hydrocarbons). However, such levels are not common in UST sites. During excavation, the peak contaminant levels are reduced, because highly contaminated soil becomes mixed with surrounding soil that is less contaminated.

- The presence of significant heavy metal concentrations (>2,500 ppm) may inhibit microbial growth.

1.3 Biopile Technology Screening and Selection. The use of a biopile to remediate petroleum hydrocarbon contamination from soil is generally applicable under the following conditions:

- Soil is contaminated primarily with petroleum hydrocarbons.
- Chlorinated or recalcitrant organic compounds are present in negligible amounts.
- Toxic metal concentration is below 2,500 mg/kg soil.
- The total soil volume to be treated is greater than 250 yd^3.
- There are multiple sources of TPH-contaminated soil to be treated that can total more than 250 yd^3.
- The TPH treatment target levels usually range from 500 to 1,000 mg/kg of soil. Actual target levels should be negotiated with the appropriate regulatory agency on a site-by-site basis.

The bulleted conditions listed above serve as guidelines and are not hard and fast rules. Site-specific conditions may dictate when biopile treatment may be a successful alternative. However, under normal circumstances, the above-cited conditions should be viewed as the primary qualifying guidelines in evaluating whether or not to pursue the use of a biopile system. In any event, the project manager should conduct economic and technological assessments. This document has been designed to give the project manager the required information to make a sound technological evaluation of the applicability of a biopile for a specific soil remediation need. The project manager can use the decision tree shown in Figure 1 to properly screen the feasibility of a biopile system. This decision tree is predicated on the above-listed bulleted conditions.

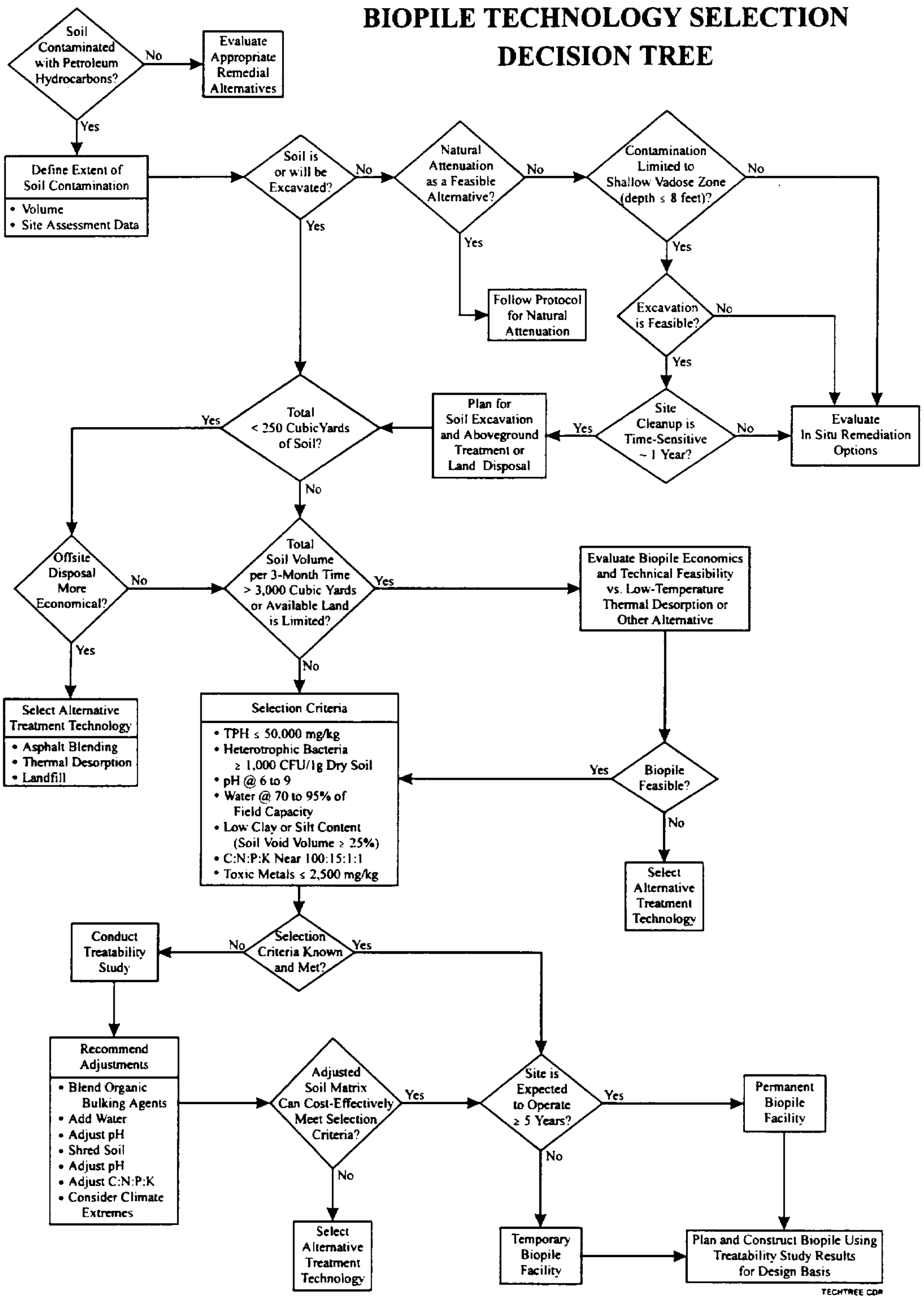


Figure 1. Biopile Technology Selection Decision Tree.

1.4 Scope of the Manual. This manual is intended to provide technical guidance on the design, operation, and maintenance of biopiles to remediate soils contaminated with petroleum-based organic contaminants. The design and construction manual is followed by a companion document that includes procedures for operation and maintenance. The design and construction manual focuses on engineering-related considerations for biopiles. It does not provide detailed design specifications and civil engineering construction details (e.g., design and construction of concrete pads). Such information should be site-specific and the reader should seek local engineering guidance.

The design and construction manual consists of seven sections. Section 2.0 provides background on the biopile concept from a literature review and case histories. Section 3.0 presents the regulatory issues and permitting strategy. Section 4.0 describes how to profile soils to determine their applicability to remediation in biopiles. Section 5.0 presents preliminary design information, and Section 6.0 provides the design and construction specifications for a baseline biopile volume of 500 yd^3 (382 m^3). Section 7.0 lists references cited in text. Appendices A through J provide supplementary information to assist the designer.

Section 2.0: TECHNOLOGY OVERVIEW

This section introduces the technical basis for biopile design by describing prior applications of biopiles to the treatment of contaminated soils. Information about past experience with biopiles is organized into eight groupings based on major functional elements of biopile systems. These elements are as follows:

- site preparation
- base preparation
- leachate collection
- aeration
- moisture addition
- nutrient addition
- microbial amendment
- general construction.

Biopile treatment is a controlled biological process where biodegradable contaminants are converted to their basic mineral constituents (water and carbon dioxide) under aerobic conditions. Soil is excavated, prepared, formed into a biopile, and aerated to promote biodegradation. In most cases, the biodegradation is achieved by indigenous microorganisms. Maximum degradation efficiency is achieved by maintaining the moisture content, pH, aeration, temperature, and carbon-to-nitrogen ratio (DOD, 1994). Terms used to describe biopile design are defined in Appendix A.

2.1 **Site Preparation.** The selected site must provide adequate space, infrastructure, and support services for the biopile. A flat area, free of obstructions, is needed for soil handling and pile construction. The site serves as the subgrade for the base that carries the weight of the biopile and associated soil handling and preparation equipment. Roads and bridges leading to the site must be capable of carrying legal-weight, legal-length trucks with a gross vehicle weight of 40 tons (36 tonnes) and an approximate maximum payload of 24 tons (22 tonnes). Space is required for stockpiling, mixing, and preparing soil as well as for the biopile. Electrical service will be needed to operate equipment such as blowers, pumps, and instruments. A 480-V, 3-phase electrical supply is desirable if the blower size is over 2 hp, and is strongly recommended when the blower size is over 4 hp. In addition, 110-V single-phase service is desirable to operate small pumps and AC-powered instruments.

2.2 **Base Preparation.** The base of the biopile serves three main functions:

- It provides a stable foundation to support the biopile and associated soil handling operations.
- It provides a barrier against potential migration of contaminants into the underlying soil.
- It provides a 1% grade to avoid pooling of leachate at the base of the biopile.

The biopile base may be newly laid or the pile may be built on an existing foundation such as a parking lot or a storage yard. A new base for a permanent facility may be constructed from Portland cement concrete or bituminous paving. To lower the potential for contaminant migration, either type of base normally would be covered with an impervious liner (Kamnikar, 1992) and (Brown and Cartwright, 1990). For a permanent biopile, the impervious liner may be placed beneath the compacted soil foundation of the concrete pad. The base for a temporary biopile may be constructed using a compacted soil or clay and should be covered by a replaceable impervious liner (Brown and Cartwright, 1990). Using an existing paved area for the biopile reduces construction costs but requires special provisions for underdrains and sloping to collect leachate.

2.3 **Leachate Collection.** For a permanent biopile site, a leachate collection system should be installed. The leachate collection system usually includes a containment berm or structure around the pile, perforated pipe at low points in the fill, a leachate collection pump connected to the drain piping, and a leachate collection tank.

For smaller biopiles, the leachate collection system can be incorporated into the vapor extraction system. Experience has shown that most water will flow to the aeration pipes. Very little or no leachate would flow to a low-point leachate collection sump in a covered pile system. Using this type of design, a liquid-knockout tank is installed in the vapor extraction manifold ahead of the blower. A small vacuum pump is then periodically used to pump the water from the knockout tank to the leachate collection tank. Figure 2 presents a schematic of a leachate collection system incorporated with the aeration system.

2.4 **Aeration.** The biopile must be adequately aerated to support efficient degradation of contaminants by microorganisms. Of all the metabolic factors, oxygen is the most important, so efficient aeration is essential to biopile success. Both active and passive air supply systems have been used successfully (Brown and Cartwright, 1990; Kamnikar, 1992).

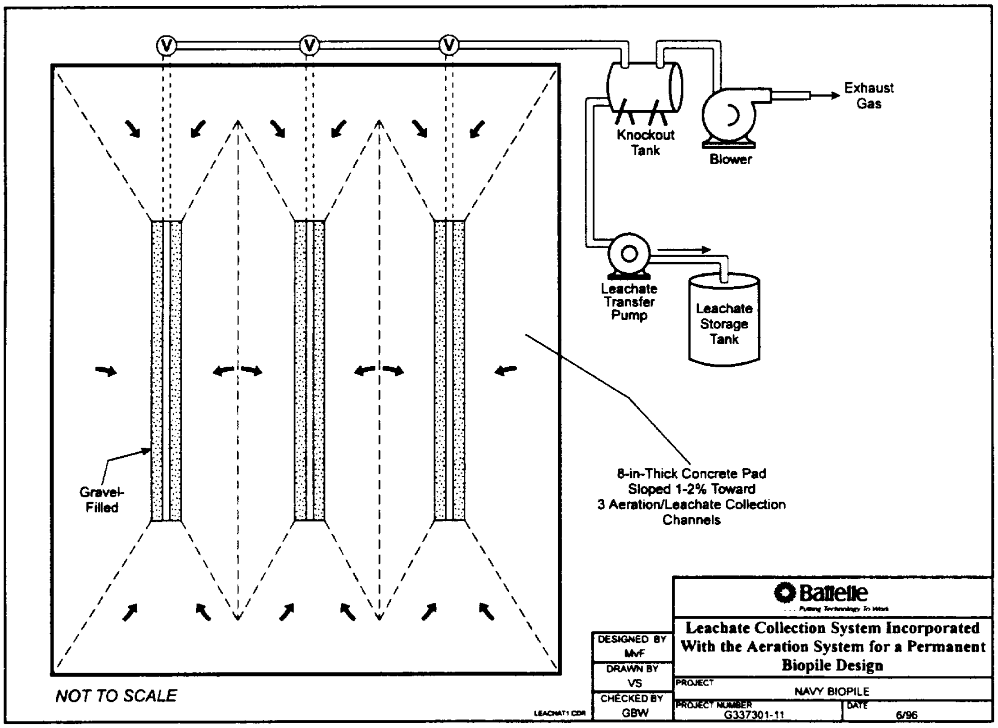


Figure 2. Leachate Collection System Incorporated with an Aeration System for a Permanent Biopile Design.

The simplest method of pile aeration is a passive system. Drain tiles, perforated tubing, or slotted pipes are placed at various heights throughout the pile. The tiles or pipes are long enough so their ends stick out of the pile, allowing air transfer and venting due to natural currents (Kamnikar, 1992). The passive method reduces capital and operating costs because no blower is required, and reduces the potential for drying the pile because the airflow rate is low.

Despite the lower cost for passive aeration systems, active aeration is preferred, because it gives more complete and more controllable airflow that speeds bioremediation in the pile. Two active aeration configurations have been used: air injection and air extraction. Both configurations have perforated pipes located in the pile that are connected to a blower to push air into the pile (injection) or to pull air through and out of the pile (extraction). Typically, airflow rates through the pile are just great enough to keep the soil above oxygen-limiting conditions. Such flowrates prevent excess volatilization of hydrocarbons, thus reducing the vapor emissions from the pile. One method for determining the required airflowrate is presented in Leeson and Hinchee (1995). Although this method was developed for in situ treatment of hydrocarbons, it can be used for biopile facilities. The PILEFLOW computer modeling method for biopiles (NFESC, 1996c) is a more relevant airflow modeling method. The PILEFLOW model is described in Appendix K.

The contaminant volatilization rate also is dependent on the type of contaminant present in the biopile. Operating in the extraction configuration often is preferred when volatilization of organic compounds is a concern (Hayes et al., 1995). In the extraction configuration, emissions from the pile can be collected and controlled. Extracted air from the blower outlet is passed through a treatment system to destroy contaminant vapors. Granular activated carbon (GAC) historically has been used at biopile sites for the treatment of discharge vapors.

When the TPH contamination is a heavier fuel (diesel or heavier), off-gas treatment may not be necessary. The TPH concentration in the biopile exhaust air will rapidly decline as the minor, lighter hydrocarbon fraction is depleted. Chaudhry (1996), for example, reported a decline of TPH in biopile exhaust air from an initial 733 ppmv to below 2 ppmv within 3 weeks of system startup. Efforts should be made to negotiate with regulators not to require biopile off-gas treatment in cases where the primary contaminant is a heavier hydrocarbon. In some cases, initial vapor treatment followed by no vapor treatment may be an appropriate option. Vapor treatment could be stopped once TPH concentrations in the biopile exhaust have decreased below a negotiated level.

2.5 Moisture Addition. Water must be available in the biopile, but the amount must not be excessive. Microorganisms require moisture to transport nutrients, to carry out metabolic processes, and to maintain cell structure. However, excessive moisture is undesirable because (a) when water occupies a high fraction of the pore space in the soil, the air permeability declines, reducing aeration efficiency; and (b) excess moisture will increase leaching of contaminants and nutrients from the pile.

The moisture content and moisture retention characteristics of soils to be treated in a biopile can readily be adjusted during the initial preparation of the soil for the biopile. At some sites, little or no initial water addition will be needed. If the moisture content is too high, dry bulking agents can be mixed with the soil. The bulking agent can be selected to increase or decrease moisture retention. Also, some data indicate that surfactant addition may improve surface wetting (U.S. EPA, 1990, EPA/540/2-90/002).

The moisture content of the biopile may change as the remediation proceeds. Air normally will enter the biopile at less than 100% relative humidity. The air will tend to remove moisture as it moves through the biopile and become saturated with water, thus reducing the moisture content. However, at the same time, the biodegradation process is converting hydrocarbons to CO_2 and H_2O, thus renewing the moisture content to some degree. Approximately 1.5 lb (0.68 kg) of H_2O is produced per 1 lb (0.45 kg) of TPH degraded. Depending on the site conditions, it may be necessary to add moisture during biopile operation. However, dry ambient air conditions and low initial hydrocarbon content together or individually tend to increase the need for moisture addition. Moisture control practices are easily implemented as long as the biopile design and installation provide for leachate collection and control.

Unless the feed air is dry, the aeration rate is excessive, or the soil organic content is low, an initial adjustment of moisture content usually is sufficient to eliminate the need for water addition during operation. Under normal conditions, a covered biopile system should be expected to lose 1 to 2% of moisture over a 3- to 4-month operating period. One biopile study used wetted wood chips and manure mixed with the soil as additional moisture sources instead of providing moisture addition during pile operation (Kamnikar, 1992). Generally, the moisture content is kept between 40 and 85% of field capacity throughout the remediation process (U.S. EPA, 1995). Although the U.S. Environmental Protection Agency (U.S. EPA) recommends that the moisture content be kept between 40 and 85% of field capacity, it is suggested that the soil be between 70 and 90% of field capacity if water is applied only during biopile construction, because it is assumed that some drying (1 to 2 weight %) will take place during the pile construction and operation.

2.6 Nutrient Addition. Biopiles work to degrade contaminants by means of the microorganisms in the pile that use the contaminants as a source of carbon and energy. The organisms need a supply of carbon to build biomass. The contaminants and natural organic compounds in the soil typically provide an adequate amount of carbon, but the availability of other essential nutrients such as nitrogen, phosphorus, or potassium may be insufficient compared to the quantity of carbon. Typically, the C:N:P ratio is brought to within the range of 100:10:1 to 100:10:0.5 (U.S. EPA, 1995).

In general, the soil should be amended with nutrients prior to biopile construction (Brown and Cartwright, 1990). The nutrients may be either dissolved in water and sprayed onto the soil prior to construction of the pile or applied in granulated form and mixed with the soil while the pile is being constructed.

Nutrients may be added during operation. The nutrient addition is combined with a moisture addition system. When the pile begins to dry out, a dilute solution of nutrients in water is applied to the top of the pile using sprays or drip irrigation systems. The nutrient solution then percolates down through the pile (Brown and Cartwright, 1990). Nitrogen permeates through to the bottom of the pile; however, phosphorus generally travels down 1 to 2 ft due to chemical reactions with the soil.

Biopile systems have been designed to irrigate the pile with water recovered in the leachate collection system. In most cases, the water is pumped from the leachate collection tank and is recycled to the pile using a drip-type irrigation line (USACE, 1995).

2.7 Microbial Amendment . Some biopile designs have included the addition of microbes along with the nutrients. The microbial amendment is added to the nutrient solution and is sprayed onto the soil in preparation for biopile construction. The organisms are naturally occurring but are claimed to be specially cultured to optimize hydrocarbon degradation (Shaw et al., 1995). Microbial amendments increase the overall cost and have not been clearly demonstrated to improve the degradation of petroleum hydrocarbons. Amendments such as white-rot fungi may be necessary to degrade recalcitrant compounds, but most biopile users reject the addition of exogenous microbes. Many studies indicate that indigenous microorganisms are capable of successfully degrading petroleum hydrocarbon contaminants (Hinchee et al., 1992).

2.8 General Construction . Most soils will require the addition of water (see Section 2.5) and nutrients (see Section 2.6) and will then be ready to be treated. In some cases, the nutrient and water contents of the soil to be treated are adequate and the grain size is coarse enough to provide good air permeability without adding anything to the soil.

In soils with a high clay content, soil shredding and/or blending with a bulking agent may be needed to improve the soil structure and porosity. Typical bulking agents are wood chips or sand (Brown and Cartwright, 1990). Prior to any soil shredding, a screening step should occur to remove rocks and debris. The typical treatment train to prepare soils requiring the addition of bulking agents includes the use of a set of parallel metal bars (grizzly) for bulk separation followed by soil shredding and then addition of water and nutrients. Figure 3 gives a schematic of such a soil preparation process. The equipment and procedures to mix soil range from basic to complex. In the simplest system, thin layers of soil and bulking agent are interspersed, wetted, and then lifted and dropped using a front-end loader (Kamnikar, 1992). If a higher throughput or better control of volatile emissions is required, a faster mixer with a better seal, such as a pug mill, may be used. Crushing and mixing of the soil may be desirable to increase the contaminant homogeneity and improve the soil permeability and may eliminate the need to add a bulking agent (Eiermann and Bolliger, 1995).

The soil, as received (most cases) or as processed (in cases where soil shredding or bulking agents are required), is mixed with the appropriate amounts nutrients and water as the soil lifts are added to the biopile foundation. The nutrients may be added as part of a metered water-spray solution or may be added dry in measured quantities as each additional bucket of soil from the is unloaded on the biopile. The amount of water and nutrients to add per bucket load is a function of the size of the bucket. The biopile ingredients must be blended in the correct ratios for optimum biodegradation of the contaminants before or during pile construction (see Section 2.6). The pile is then arranged to allow efficient aeration while minimizing contaminant and odor release and controlling the internal temperature.

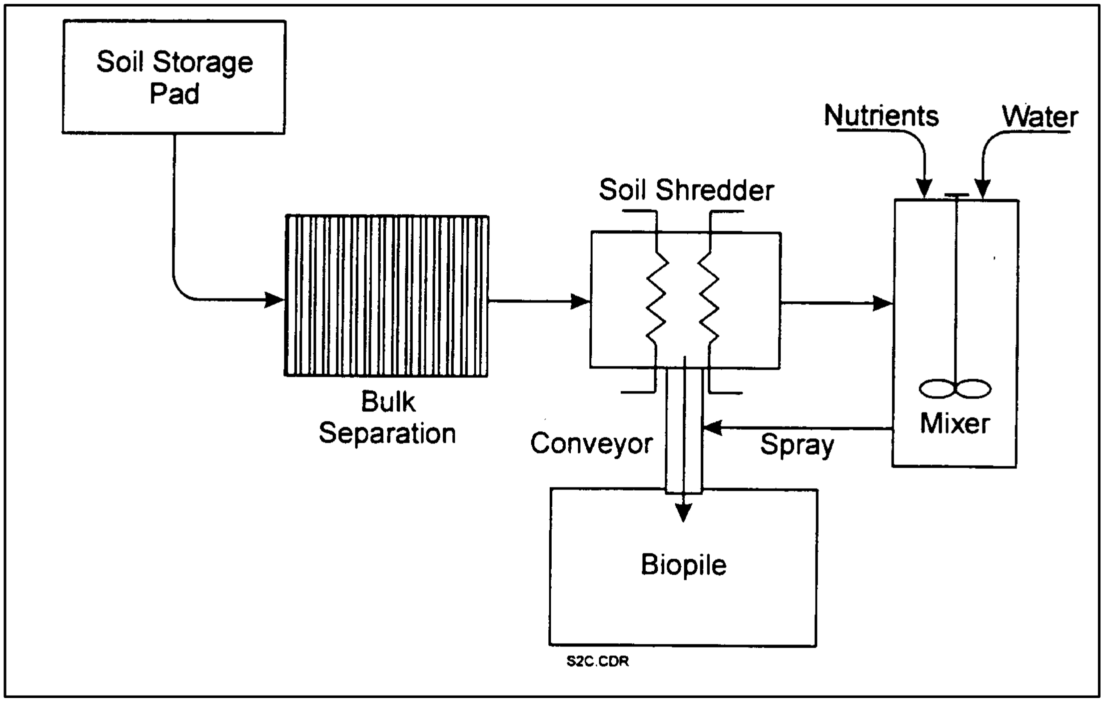


Figure 3. Soil Processing Equipment Train.

The construction details of biopiles are flexible. Effective biopiles have been built in a wide variety of sizes and shapes. Historically, biopile dimensions have been constrained more by space availability and logistics than by size-based performance limitations. Although a wide range of sizes and shapes have been used, biopile construction complexity increases significantly when the pile dimensions exceed the reach of a front-end loader. Thus, biopile dimensions usually do not exceed a height of 8 ft (2.4 m). There are no general length or width restrictions, but the front-end loader must avoid driving over previous lifts.

The task of evenly aerating the pile influences the size and shape of the biopile. Tall piles (>10 ft [>3 m]) generally require more than one level of aeration pipes, thus complicating the construction process. When installing multilevel aeration systems, the aeration pipes frequently are placed on top of each layer of soil and covered by the next layer so that the pipes are located at various heights within the pile. Experience, however, indicates that a single set of aeration pipes located at the bottom of the pile is adequate for piles up to about 8 to 10 ft (2.4 to 3.0 m) high (Figure 4). Aeration pipes must be arranged so that they are not crushed by earth-moving equipment. To avoid compacting the biopile, earth-moving equipment should never be allowed to travel over the soil in the pile.

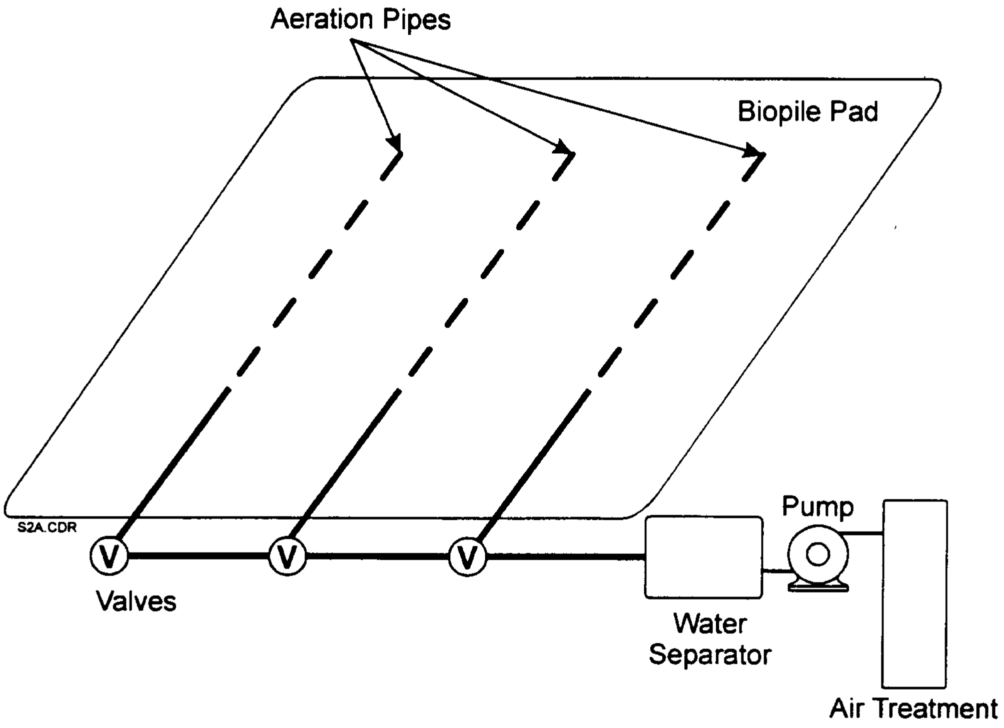


Figure 4. Layout of a Typical Biopile Aeration System.

Biopile construction typically includes installation of instruments within the pile to monitor critical parameters. The most essential monitoring provisions are tubes for sampling gas in the pile and thermocouples to measure temperature (Kamnikar, 1992).

After the pile is formed, it should be covered. The cover serves to protect the biodegrading soil from the elements to:

- retain moisture
- retain heat
- prevent excessive, sudden water addition from rain
- prevent wind from blowing dust from the pile
- prevent cementation of upper soil layer from wetting and drying.

Plastic sheeting material held down by old tires, sand bags, or weighted netting is often selected as a low-cost, effective approach for biopile protection (Brown and Cartwright, 1990). A successful method of securing the cover, developed by the Navy, uses nylon rope to hold down the cover. The rope is held in place by passing it through eye-bolts screwed into the biopile berm. In a few cases, an existing building has been used, or an inexpensive structure such as a pole barn or sheet metal building has been built in lieu of a cover.

Proper construction of the biopiles is important to avoid excessive internal temperatures (Shaw et al., 1995). Biological degradation of contaminants releases heat in the same way combustion would, but at a lower rate. The heat release increases the biopile temperature during operation. Some temperature rise is desirable to enhance the microbial degradation rate, but an excessive temperature increase is undesirable because bioactivity declines after the optimum temperature is reached. The typical target temperature falls in the range of 68 to 104°F (20 to 40°C) (Lei et al., 1994).

The biopile construction design should include plans for demobilization and decontamination. When soil treatment is complete, the equipment should be cleaned and removed, and the site restored.

Section 3.0: REGULATORY ISSUES AND PERMITTING STRATEGY

Before a remedial action is taken, regulatory research must be performed to determine which regulations will govern the site. The project officer must be familiar with the site geography and topography as well as the type of contamination, the contaminated medium, and the remediation method to be used to know which regulations may apply. Additionally, an understanding of potentially relevant environmental regulations will be useful in mapping out the permitting approach for the specific site.

3.1 Regulatory Issues . Environmental regulations are categorized as chemical-specific, location-specific, and action-specific regulations. Each type may be issued at the federal, state, or local level. Examples of chemical-specific regulations include the federal Clean Air Act and Clean Water Act which set numerical limits on the emissions and discharges of specific substances. Some chemical-specific regulations also specify target cleanup limits. Location-specific regulations include laws protecting site-specific resources such as endangered wildlife, wetlands, and wilderness areas. Action-specific regulations apply to specific activities or technologies and include monitoring requirements, effluent and leachate discharge limits from specific processes, and worker health and safety requirements. The water and air discharges from biopiles are required to meet the permitting standards of the local jurisdiction. Appendix B describes the major federal environmental policy acts and regulations and provides a tabular listing of various chemical-, location-, and action-specific regulations.

Time must be budgeted within the remediation plan to allow for the regulatory research and permitting processes. It may take weeks or months after identifying the lead regulatory agency to obtain the permits required to begin a bioremediation action. Every stage of the cleanup effort from planning to shutdown must be coordinated with the appropriate regulators.

3.2 Permitting Strategy . This section describes a general strategy for working with environmental regulatory agencies and obtaining the proper permits to implement bioremediation projects such as biopiles. Figure 5 illustrates the elements of the permitting process.

It is important to have the potential regulatory agencies involved in the permitting process while the biopile is still in the planning stages. The project officer should use the following steps as a guideline to execute the permitting process:

Step 1. Establish the contamination type, contamination level, and amount of soil to be remediated.
Step 2. Decide on the treatment alternative(s) using the decision tree in Section 1.
Step 3. Select a tentative treatment location.
Step 4. Prepare a tentative work plan.
Step 5. Identify and contact applicable regulatory agencies.
Step 6 Through meetings and correspondence, determine the lead regulatory agency.

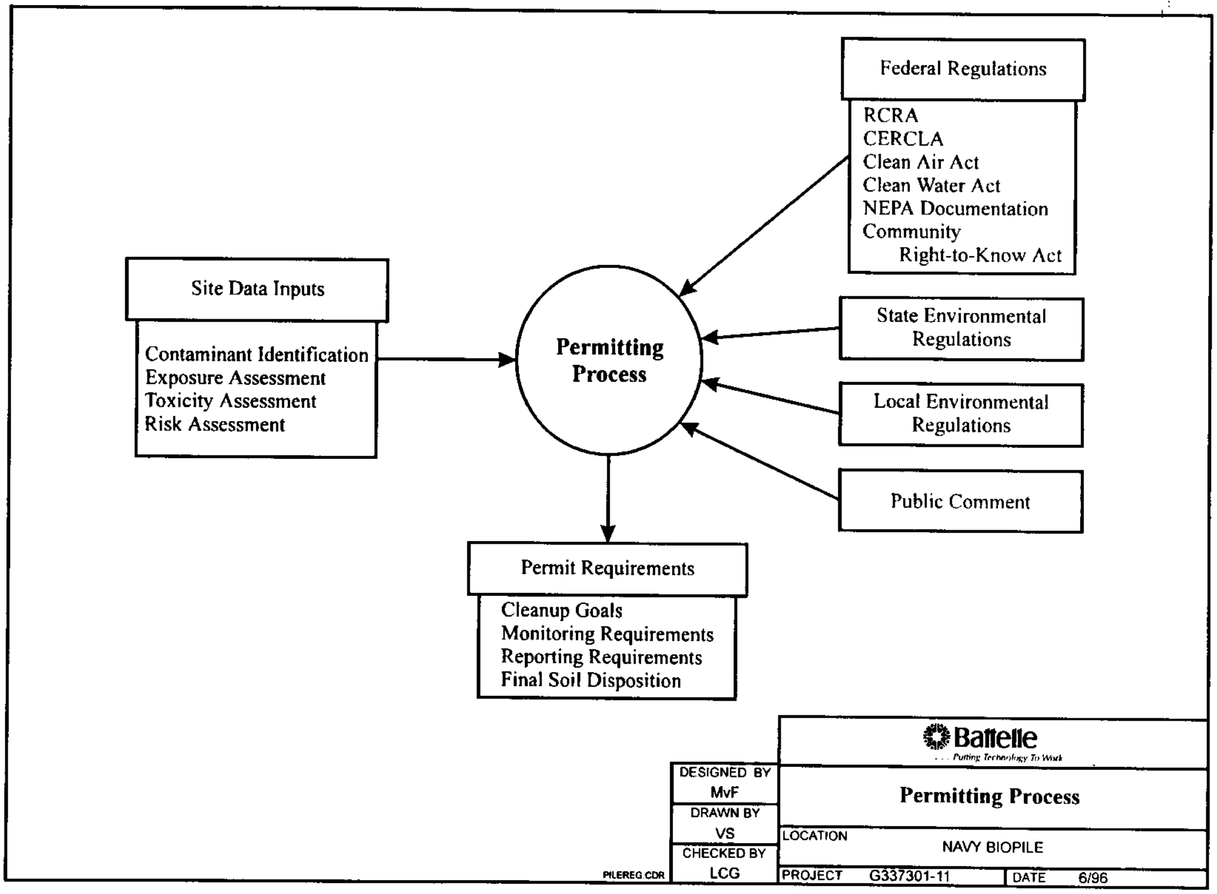


Figure 5. Permitting Process.

Step 7. Negotiate the target cleanup levels and final soil disposition with the lead agency. Obtain a written memo from the regulatory agency confirming the agreed-upon cleanup levels, and all documentation and permits that will be required for the project.

Step 8. Work through the lead agency to obtain the proper permits.

Step 9. Coordinate the site preparation and soil remediation plan with the base environmental and facilities departments. Be sure to include plans for final soil transportation, disposition, and sitecloseout.

Step 10. Inform other agencies as necessary of planned remediation activities.

The U.S. EPA and state environmental protection agencies, as well as local water and air quality boards and the landfill authority, may simultaneously regulate remediation efforts. When regulations of different governmental levels overlap, the most stringent regulation applies. Rather than coordinating a remediation plan through every one of these agencies, the jurisdiction of each agency should be compared to the applicable environmental risk of the contamination and to the site. The most relevant agency should be identified as the lead agency. Once the lead agency is known, relevant regulatory matters can be handled with it directly, while keeping the other regulatory organizations informed of the situation through mail or meetings.

Before initiating communications with regulators, the biopile project officer should prepare a tentative work plan outlining the nature and extent of the contamination, proposed biopile location, preliminary remediation timetable, and proposed final soil disposition. A good work plan will facilitate the regulatory evaluation of the proposed remediation effort and may reduce the overall time required to complete the permitting process.

Part of the regulatory process involves negotiating with the lead agency to set the target cleanup levels to be achieved through the proposed remediation. Prior to biopile construction, target cleanup levels should be negotiated with the lead agency based on the type of contaminant, extent of contamination, and limits of the technology. Sometimes the chosen cleanup levels are set based on public drinking water standards or Resource Conservation and Recovery Act (RCRA) Land Disposal Restriction (LDR) requirements. However, higher concentrations may be acceptable if risk-based analysis shows that the concentration is protective of human health and the environment.

To be acceptable, remediation of the biopile must be able to reach the required cleanup limits. For a biopile, the target cleanup level for total petroleum hydrocarbon (TPH) contamination generally is in the range of 500 to 1,000 ppm for a 3-month treatment cycle. Levels of 100 to 500 ppm may be achievable for longer treatment periods (4 to 6 months). The actual target cleanup level is dependent on the initial TPH contamination level, soil type, desired final soil disposition, and the applicable regulatory agency's specifications. When the target cleanup level has been established, the biopile project officer should request a written letter from the agency point of contact specifying the agreed-upon target cleanup level and the corresponding method of final soil disposition.

After establishing the target cleanup level, the project officer continues to coordinate and complete the permitting process. Once all applicable permits have been obtained, the work plan can be finalized by coordinating the biopile design and site requirements with the base environmental and facilities offices. Plans for final soil transport and disposition in accordance with the site permits must be in place prior to the start of construction. Copies of the final work plan may be sent to the appropriate regulators and base officials, as necessary.

Appendix C contains a list of the hazardous waste management contacts for each state. Appendix D contains a list of the addresses and phone numbers of the U.S. EPA Regional Offices throughout the country.

Section 4.0: PROFILE OF EXISTING CONTAMINATED SOILS

The media of concern for this design and construction manual are soils contaminated with petroleum hydrocarbons. These materials are hydrocarbon products with minor additives specific to each product's application and consist mainly of straight-chain and cyclic organic compounds. Biopile remediation is most likely to be applicable when petroleum hydrocarbon contamination sources are limited to soil depths shallower than 8 ft. In general, in situ treatment is applied at deep or very large contaminated sites, and ex situ treatment is used for smaller sites or multiple sites needing a central treatment area.

4.1 Contaminant Sources and Distribution. The hydrocarbon contaminants may enter the environment as a result of events such as leaks, spills, or discharges at the surface; use in fire training pits; or leaks from underground storage tanks (USTs) or piping. Unless the release occurs in nonsorptive, porous soils (e.g., sands), the bulk of the petroleum contaminants entering the environment will not migrate far from the original source. Thus contaminants from leaks, spills, discharges, or fire training pits typically will remain in surface soils where they are accessible for excavation and biopile treatment. Leaks from buried piping or USTs will contaminate deeper soils.

A hydrocarbon release can result in the migration of contaminants to any of four phases in the soil:

- as a sorbed phase on soil surfaces in the vadose zone (soil above the water table)
- in the vapor phase in the vadose zone
- as light, nonaqueous-phase liquid (LNAPL) either floating on the water table or as residual saturation in the vadose zone
- in the water phase dissolved in pore water or groundwater.

A conceptual model of the distribution of hydrocarbon contaminants is illustrated in Figure 6.

Although petroleum contaminants dissolved in the groundwater frequently pose the greatest risk through the drinking water pathway, residual and sorbed LNAPL act as the source for contaminants to the groundwater and vapors. The biopile remediation technology reduces risks to human health and the environment by excavation and treatment of soils containing sorbed or residual hydrocarbons.

4.2 Contaminant Properties. The success of biopile remediation depends largely on the contaminant characteristics. Petroleum hydrocarbons such as gasoline, diesel fuel, lubricants, or crude oil contain various types of organic compounds as illustrated in Figure 7. Crude oils may contain large fractions of polar asphaltenes and resins containing nitrogen, sulfur, or oxygen. Refined products such as petroleum hydrocarbon fuels and waste oils contain mainly saturated and unsaturated hydrocarbons. Some physical and chemical properties of typical components in petroleum hydrocarbons are compiled in Appendix E.

Gasoline is a fuel consisting of lighter fractions of petroleum. The composition of gasoline typically ranges from 4 to 8% alkanes, 2 to 5% alkenes, 25 to 40% isoalkanes, 3 to 7% cycloalkanes, 1 to 4% cycloalkenes, and 20 to 50% aromatics (0.5 to 2.5% benzene) (U.S. Department of Health & Human Services, 1993a).

Diesel fuel contains mainly hydrocarbons with 10 to 19 carbon atoms. The approximate composition ranges for diesel fuels are 64% aliphatics, 1 to 2% olefins, and 35% aromatics. Gasoline and diesel fuels contain less than 5% polycyclic aromatic hydrocarbons (PAHs). Heavier fuel oils contain a higher proportion of hydrocarbons with more carbons in the compound. The heavier fuels also may contain more than 5% PAHs (U.S. Department of Health & Human Services, 1993b).

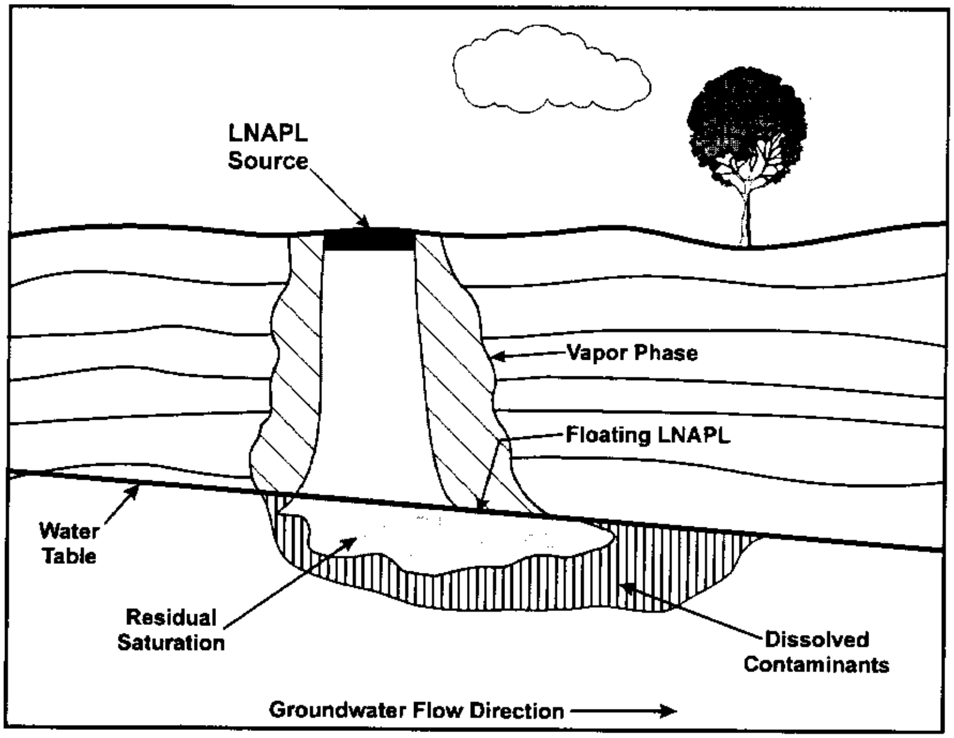
Jet fuel-4 (JP-4) is a widely used fuel containing petroleum hydrocarbons with carbon chain lengths in the range of 4 to 16. A typical average composition for JP-4 is 32% normal alkanes, 31% branched alkanes, 16%

cycloalkanes, 18% benzenes and alkylbenzenes, and 3% naphthalenes. JP-5 is similar to JP-4 but has a much lower content of benzene, toluene, ethylbenzene, and xylenes (BTEX). Jet fuel-7 (JP-7) is a similar petroleum hydrocarbon fuel but has a narrower boiling range and lower allowed content of aromatic compounds (U.S. Department of Health & Human Services, 1993c).

To be amenable to treatment in a biopile, a compound must biodegrade (a) under aerobic conditions at a rate fast enough to allow for remediation in a few months and (b) at a sufficient rate relative to the vaporization rate to allow for biodegradation to predominate over volatilization. Figure 8 shows the relationship between contaminant vapor pressure and aerobic biodegradability. The data shown in Figure 8 indicate the general trends for biodegradability for a selection of organic contaminants. These data indicate that biopile treatment is promising for most of the components in jet fuel or diesel fuel based on their pressure and biodegradation rate.

Treatment of soils contaminated with fresh gasoline may require special design provisions due to the high content of BTEX. The BTEX compounds have high biodegradation rates, but they are volatile and more strictly regulated than other components of petroleum hydrocarbons. The actual biodegradation rates achieved will vary substantially depending on the contaminant concentration, the matrix properties, and the conditions in the biopile. In some cases, treatability testing will be required to evaluate the feasibility of biopile treatment and to determine design parameters. Treatability testing is discussed further in Section 5.1.

4.3 Soil Properties. Soils consist of weathered mineral grains and organic materials in varying proportions. Soils typically are heterogeneous and may be stratified due to historical variations during the soil formation process. Soil layers form as a result of interactions between the soil and groundwater, atmosphere, and vegetation. The properties of the upper layers are particularly affected by the biological activities of plants and microorganisms. As a result, the surface soil properties are strongly influenced by soil chemistry, moisture content, and climatic conditions.



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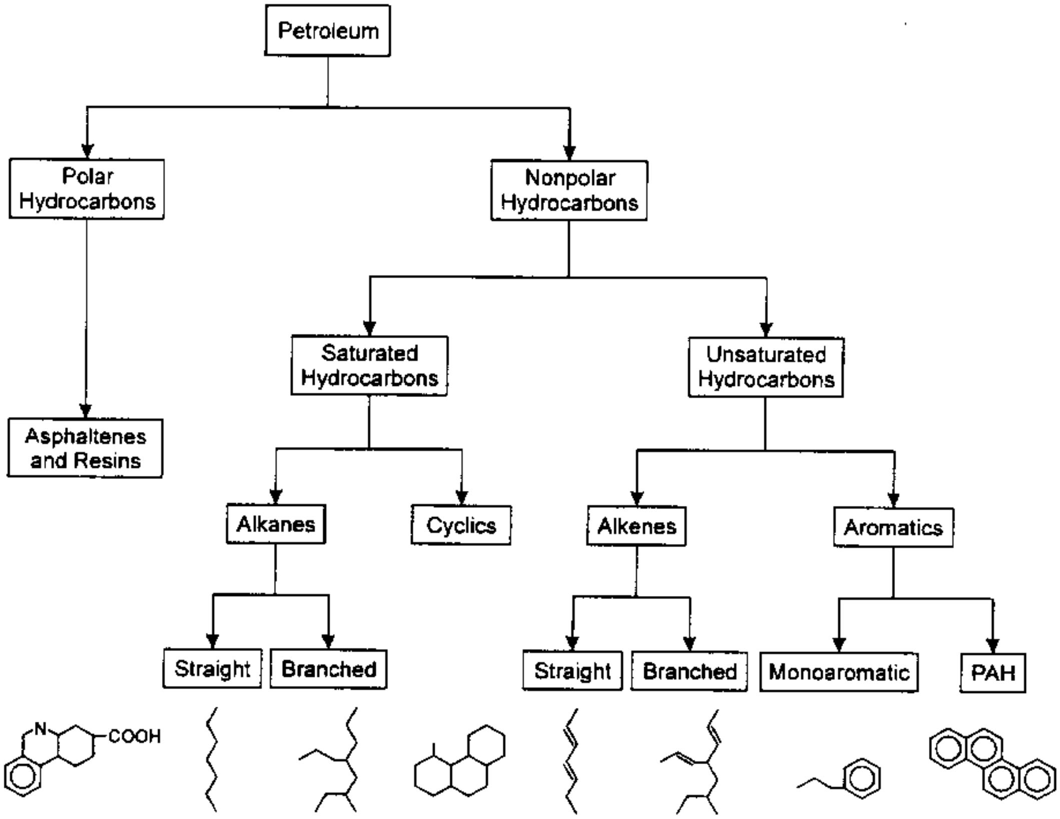
. . . Putting Technology To Work

Contaminant Distribution at a Typical Hydrocarbon-Contaminated Site

DESIGNED BY AL	PROJECT NAVY BIOPILE	
DRAWN BY VS		
CHECKED BY LS	PROJECT NUMBER G337301-11	DATE 6/96

LNAPL04 CDR

Figure 6. Conceptual Model of the Distribution of Contaminants.



Source: Adapted from Huesemann, 1994

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. . . Putting Technology To Work

Illustration of the Types of Compounds in Petroleum

DESIGNED BY LS		
DRAWN BY VS	PROJECT NAVY BIOPILE	
CHECKED BY LCG	PROJECT NUMBER G337301-11	DATE 6/96

PETRO1.CDR

Figure 7. Illustration of the Types of Organic Compounds in Petroleum.

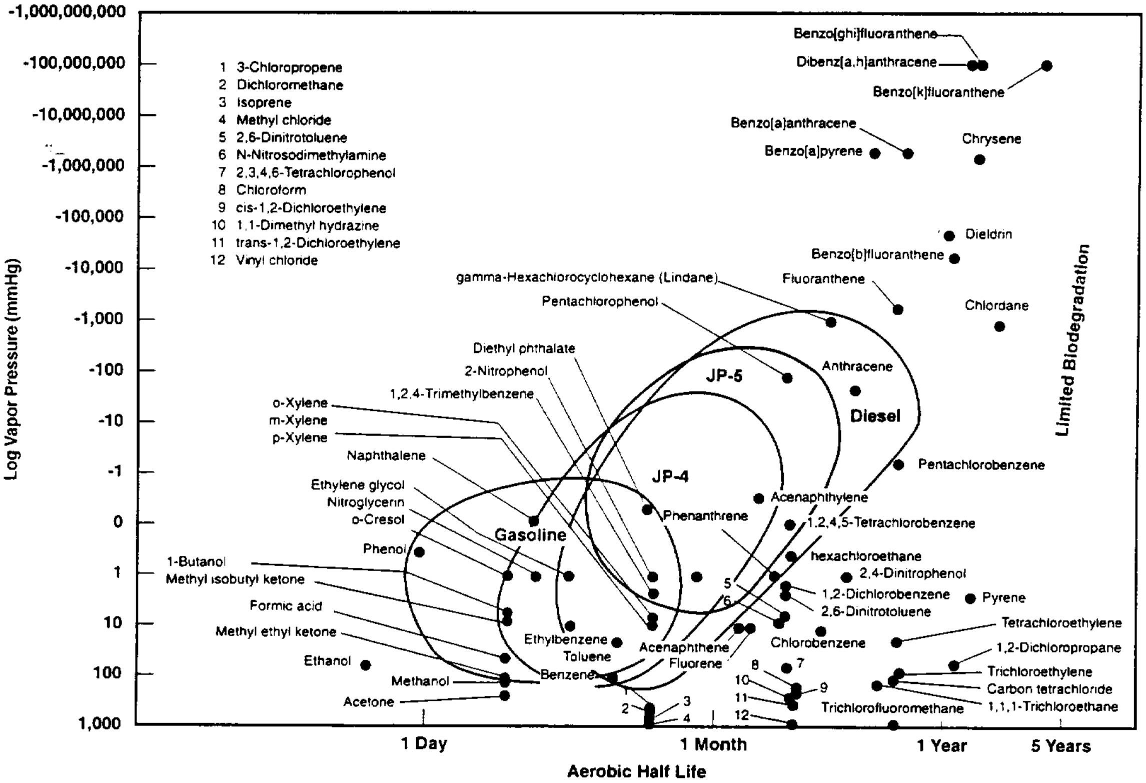


Figure 8. Relationship Between Contaminant Vapor Pressure and Aerobic Biogegradability.

The wide variations in natural soil properties and contaminant distribution encountered at sites cannot be overemphasized. Not only do soil and contaminant conditions vary widely from site to site, but wide ranges of conditions frequently occur within one site. The equipment selected to handle contaminated soils at the biopile site must be able to accept these wide variations.

The permeability and sorptive properties of the soil depend on the soil type. Many systems have been established to classify soil types and constituents. Most of these classifications include particle size as the primary physical parameter. Typical classifications, in order of decreasing size, are: gravel, sand, silt, and clay.

A high clay content in the soil will adversely affect biodegradation processes in the biopile in two ways. First, a high clay content will reduce the permeability of the soil and thus increase the difficulty of adequately and uniformly aerating the pile. Also, a high clay content may decrease the availability of the organic contaminants and thus decrease the biodegradation rate because clay strongly adsorbs organic contaminants, reducing the biological availability of the contaminants (Huesemann, 1994).

Movement of air in the biopile occurs primarily through the gas-filled pores. The amount and configuration of soil porosity are important determinants of the gas permeability of the soil. Soils with connected porosity generally are more amenable to treatment in a biopile. The soil permeability or porosity can be increased by adding bulking agents or by soil shredding, if needed.

The organic content of soil can vary from less than 1% in dry, sandy soils to more than 20% in soils that are exposed to water much of the time. The chemistry of the organic portion of soils is complex. The soil organic content will consist of high-molecular-weight humic materials and lower-molecular-weight organic acids and bases.

The high-molecular-weight humic materials have low water solubility and high affinity for organic and inorganic contaminants.

4.4 Influence of Soil Properties on Biopile Treatment. Soil properties also affect the rate of biodegradation. Biopile remediation is conducted ex situ so amendments can be added prior to forming the pile, and the pile conditions can be controlled to overcome some of the limitations caused by the soil properties. The following soil properties most affect the biodegradation rate: moisture content, pH, nutrient supply, and metal content.

These soil properties are discussed in Sections 4.4.1 through 4.4.4, respectively.

4.4.1 Moisture Content. The soil must contain enough moisture to encourage growth of the hydrocarbon-degrading microorganisms, but not so much as to reduce soil permeability. Water is essential for biological processes because it not only provides the transport medium for the chemicals that supply energy and nutrients to the microorganisms but also enables the metabolic processes to proceed. However, excessive moisture will fill the pores in the soil pile and reduce soil permeability, making it difficult to aerate the biopile. Nevertheless, microorganisms will effectively degrade hydrocarbons over a wide range of moisture contents.

Out of 123 sites surveyed in a bioventing field study, the soils at 114 sites contained between 5% to 25% water by weight. A slight increase in biodegradation with increasing moisture was detected, but the results did not show a strong correlation between the biodegradation rate and moisture content (Leeson and Hinchee, 1995). A biopile would be expected to demonstrate similar behavior with an optimum moisture range of 10% to 20% by weight and 5% to 30% being acceptable.

4.4.2 Soil pH. The soil pH may influence the bioremediation process, because soil microorganisms require a specific pH range to survive. Most bacteria function in a pH range between 5 and 9 with the optimum being slightly above 7 (Dragun, 1988). A shift in pH may result in a shift in the microbial population because each species will exhibit optimal growth at a specific pH.

Very few soils will require radical adjustment of the pH prior to forming the biopile. If soil sampling and analysis indicates that the pH is out of the optimal range, amendments can be introduced during the initial soil preparation. If the soil pH is too acidic, lime may be added to increase the pH. If the soil pH is too basic, sulfur, ammonium sulfate, or aluminum sulfate may be added to decrease the pH (Huesemann, 1994).

4.4.3 Nutrient Supply. As in the case of all living organisms, microorganisms must have specific nutrients to sustain a healthy population. The hydrocarbon contaminants present usually provide the carbon and energy sources needed for biological action in the biopile. Glucose, acetate, or citrate may be added, if an additional supply of carbon or energy is needed to maintain optimal growth (U.S. EPA, 1990, EPA/540/2-90/002). The inorganic nutrients are needed to supplement the basic carbon source and energy source needed to sustain life. Inorganic nutrients required include nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, cobalt, copper, manganese, and zinc.

Most microorganisms can efficiently extract inorganic nutrients for the soil, but their activity may be limited by the availability of some inorganic nutrients. Nitrogen, phosphorus, and potassium are required in the highest concentration and are most likely to be limiting when the carbon source, energy supply, and aeration conditions are satisfactory. Nitrogen, phosphorus, and potassium additions are particularly likely to be needed if the available carbon levels are high.

Although the air supplied to the biopile and the contaminants is consumed by biological action, the inorganic nutrients are recycled by the ecosystem. As a result, the nutrients do not have to be continually replenished. After the initial inorganic nutrient amendment is made (if needed), no further nutrient additions will be required.

4.4.4 Metal Content. High concentrations of metals will retard the bioremediation process. As discussed in Section 4.4.3, trace concentrations of some metals are essential to growth but high concentrations will have a detrimental effect. Other metals, such as arsenic and mercury, have no nutrient value and may reduce biological activity when present at low concentrations. As a general rule, the total transition and heavy metal concentration in soil to be treated should be less than 2,500 mg/kg. Higher concentrations of cationic metals may be tolerated if the soil pH is greater than 6.5 or the cation exchange capacity is high (U.S. EPA, 1983, SW-874).

Section 5.0: PREDESIGN ACTIVITIES

This chapter describes activities required to establish the essential biopile design features (Figure 9). The predesign activities are carried out to answer such questions as these:

- Does the contaminated soil meet the selection criteria for successful remediation using a biopile?
- If not, can the soil be amended to meet the biopile technology selection criteria?
- Will the biopile facility be temporary or permanent?
- How much space will the treatment system require?
- What should the project officer consider in selecting a site?
- What are the estimated treatment costs?

The biopile design presented herein has been sized to accommodate 500 yd^3 (382 m^3) of contaminated soil. This size is sufficient to handle contaminated soil generated from most UST excavations. The biopile can be made larger or additional biopile pads can be constructed to handle larger volumes. Although multiple cells can require somewhat more space than a single, larger cell, this modular approach has several advantages. Compared to designing larger systems, this modular approach enables better soil management with respect to receipt, storage, handling, and amendment of soils; prevents costly overdesign while allowing for expansion; and maintains a manageable and securable cover size. Having more than one biopile pad enables the site manager to process soils in smaller, discrete batches. Furthermore, if one shipment of soil is exceptionally difficult to treat, due to the level of contamination or other reason, it would be isolated from the rest of the soils being processed.

The 500-yd^3 (382-m^3) size is large enough to process a significant volume of soil, yet small enough to allow two workers to apply and remove the biopile cover. With larger piles, the plastic cover becomes difficult to install and remove when conducting either moisture addition or soil sampling. Another advantage of a biopile limited to approximately 500 yd^3 (382 m^3) is that a smaller pile is easier to aerate evenly than a larger pile.

5.1 **Treatability Studies .** This section discusses planning of treatability studies to determine the

PREDESIGN ACTIVITIES

·Consolidate data on soil to be treated.
·Review treatability study results.
·Read and understand provisions of the site permits.
·Develop a permit compliance checklist that highlights required actions and equipment, such as exhaust gas monitoring, site security provisions, etc.
·Calculate nutrient requirements.
·Establish whether or not soil shredding and/or blending with a bulking agent will be required.
·Based on total material (soil and, if needed, bulking agent), calculate volume to be processed.
·Identify number of biopile pads that will be needed and the approximate size of each.
·Identify labor requirements.
·Coordinate support and schedule with base facilities and applicable contractors.

Figure 9. Predesign Activities Checklist.

effectiveness of biopile treatment and to collect information to support biopile design. The effectiveness is indicated by the ability of microorganisms in the soil to degrade petroleum hydrocarbon contaminants to acceptable cleanup levels. Design information is gathered through study of the conditions in the biopile environment that enhance the health of fuel-degrading microorganisms. Laboratory information, although not an absolute guarantee of success, can substantially reduce the risk of unexpected costs or poor biopile performance. All soils received should be analyzed to characterize their contamination and to determine whether they meet the technology selection criteria. In cases where selection criteria are not met and cannot be met using simple adjustments in nutrient or water content, a treatability study may be warranted.

To determine the feasibility of biopile remediation at the intended site, the following initial data-acquisition steps must be carried out:

- Inventory the hydrocarbon type and concentration.
- Measure the population density of heterotrophic and / or hydrocarbon-degrading microorganisms.
- Measure the pH, nitrogen and phosphorus content, moisture content, and particle-size distribution of the contaminated soil. outlines each of these data requirements for biopile feasibility, indicates the selection criteria, and lists adjustment methods for meeting the selection criteria. An explanation of the sampling and analysis method used for each data requirement is given in Section 6.3.

After analyses of the parameters outlined in Table 1 have been completed, the results should be compared to the biopile selection criteria. If the initial values are consistent with the selection criteria, biopile operation can be considered a valid option for petroleum hydrocarbon contaminant removal. If the initial values are not within the selection criteria, adjustments should be made to bring each design variable to within the selection criteria. Methods for parameter adjustment are indicated in Table 1.

Table 1. Testing Required for Biopile Feasbility

Where deemed necessary, the success of the parameter modifications is evaluated by conducting

Parameter Measured	Purpose and Comments	Selection Criteria	If Above Criterion Limits	If Below Criterion Limits
TPH and concentration	Determines the nature and concentration of contaminants to be treated	TPH £50,000 mg/kg Low concentration of recalcitrant compounds, such as chlorinated organics, PAHs, and polychlorinated biphenyls (PCBs).	Dilute with uncontaminated soil or add a bulking agent	NA
TPH-degrading microorganism density	Indicates the presence of microorganisms with the potential ability to degrade the contaminants	TPH degraders ³1,000 CFU/g dry soil	NA	Verify proper nutrient ratios, H_2O content, and oxygen delivery; verify that toxic metals are <2,500 mg/kg; consider addition of organisms by way of microbial amendment.
PH	Determines the need for amendments to adjust soil pH	pH @ 6 to 9	Adjust with a cidic compound, e.g., sulfur	Adjust with basic compound, e.g., agricultural-grade lime.
Nitrogen content	Determines the need for amendments to adjust nutrient content	C/N @ 100:15	NA	Add agricultural-grade chemical fertilizer or a nitrogen-containing organic amendment.
Phosphorus content	Determines the need for amendments to adjust nutrient content	C/P @ 100:1	NA	Add agricultural-grade chemical fertilizer.
Moisture content	Determines the need for amendments to adjust moisture content	70% to 95% of field capacity	Allow soil to dry, e.g., use biopile aeration system	Add water to achieve at least 70% field capacity.
Particle-size distribution and particle-size analysis	Indicates the clay content which assists in selecting the type and quantity of bulking agent needed Indicates if soil shredding is appropriate	Low clay or silt content (soil void volume ³25%)	NA	Shred soil; add bulking agent.

NA = Not applicable.

treatability studies in the form of bench-scale flask or column reactor tests. These treatability studies should be conducted in a biological laboratory and should be designed to measure the degradation rate of the petroleum hydrocarbon contamination under aerobic conditions. The effectiveness of any recommended adjustments can be measured by comparing the results of the degradation studies from the "adjusted" soils to the "as received" soils. Several companies specializing in soil-based treatability studies are listed in Appendix F.

Pilot-scale testing provides a relatively large-scale method for evaluating the treatment effectiveness of a given technology applied to given soil conditions. This increase in scale and complexity increases the cost of the treatability study but decreases the uncertainty involved in the selection and design of the biopile treatment. Under normal circumstances, a pilot-scale test will not be required for evaluating the feasibility of the biopile technology. Pilot-scale tests should be limited to cases where extremely unusual soil characteristics exist or where novel, non-TPH contaminants are involved. If site-specific conditions warrant pilot testing and if the budget allows for the expenditure, a bench-scale and/or pilot-scale treatability study may be conducted. The study could include any or all of the following:

- biodegradation rate as a function of moisture content, nitrogen content, and phosphorus content

- biodegradation rate as a function of soil temperature

specific respiration rate and rate of carbon dioxide evolution (mineralization rate) as a function of adjusted design parameters.

A standard method for a biopile treatability study does not exist. However, well-established procedures are practiced by government and private laboratories, some of which are listed in Appendix F. Determining the optimum parameters for a biopile treatability study may involve laboratory analysis of soil samples or may require setting up a bench-scale or pilot-scale test. Additional information about planning programs for material characterization and treatability studies is provided in two U.S. EPA documents (U.S. EPA, 1992, EPA/540/R-92/071a and U.S. EPA, 1988, EPA/540/G-89/004). In addition, the NFESC document (NFESC, 1996b) cites the purpose for and gives a detailed description of each biopile design variable.

A typical sequence for biopile treatability testing would involve preliminary soil screening analyses (as given in the decision tree in Chapter 1), followed by bench-scale testing in flasks or columns, and if necessary pilot-scale testing in a small biopile, to reduce the uncertainty to acceptable levels.

Following the initial determination of feasibility, bench-scale testing can be conducted to determine optimum operating conditions. Bench-scale tests can be performed under a range of conditions to study the effects of nutrient amendments, bulking agent addition, temperature changes, or other factors on biodegradation rates. Bench-scale studies can be conducted in biometer flasks or in soil columns.

A biometer flask provides a controlled environment for a small (80- to 100-gram [2.8 to 3.5-ounce]) soil sample. Air, filtered through Ascarite$^{\text{TM}}$ to remove atmospheric CO$_2$, is slowly purged through the flask to maintain aerobic conditions. The O$_2$ and CO$_2$ concentrations in the headspace are measured periodically to monitor the rate of biological activity.

A soil column test is conducted by placing a soil sample in a glass or plexiglass column that is 2 to 4 inches (5.1 to 10.2 cm) in diameter and 6 to 36 inches (15.1 to 90.6 cm) long. As with the biometer flask, filtered air is slowly purged through the column. The O$_2$, CO$_2$, and TPH concentrations in the exit air are measured periodically.

If the soil or contaminants present unusual problems or if the biopile will include new, unproven design features, a pilot-scale test may be appropriate. The pilot-scale tests will explore a narrow range of operating conditions defined by results from the bench-scale testing. The pilot-scale tests should be conducted using a test apparatus that incorporates the main features of the planned biopile but uses a smaller volume of soil. The pilot-scale test typically will include extensive sampling and analysis and more on-line monitoring equipment than the production pile.

As stated previously, a pilot-scale test typically is not required to evaluate the feasibility of the biopile technology. A decision to perform more complex or larger scale studies requires a trade-off between the cost to perform the study and the reduced uncertainty provided by the study. Usually this trade-off favors pilot-scale testing if the contamination, the soil, or the site conditions are of an unusual, unproven nature.

Performing a treatability study for each unit at a facility may not be appropriate. A decision to perform a treatability study and selection of the scale of the study depend on site-specific conditions. The presence of a limited number of contaminants in a homogeneous matrix tends to reduce the uncertainty about the potential performance of biopile treatment and thus reduces the need for testing. A treatability study may not be needed, if results can be extrapolated from studies on similar soils with similar contaminants and concentrations. Data available from literature sources or studies performed at other locations at the facility may give sufficient confidence to allow selection or design of the biopile treatment option. For example, little or no testing would be required when considering biopile treatment for sandy soils contaminated with low to moderate concentrations of light hydrocarbon fuels, provided that the selection criteria outlined in Figure 1 can be met.

The scope of this document is limited to the aerobic treatment of soils contaminated with nonchlorinated petroleum hydrocarbons. Other contaminants, such as high-molecular-weight PAHs, pesticides, and chlorinated hydrocarbons, are beyond the scope of this document and would require more extensive treatment studies.

5.2 Decision Between Temporary and Permanent Site . Biopiles can be constructed as either temporary or permanent facilities. The main difference between these two options is the design of the soil storage and biopile pads. For temporary biopiles, the pads can be built on an existing asphalt or concrete surface or may be built on a compacted soil or clay foundation. A permanent biopile would be constructed on a concrete foundation specifically constructed for the biopile. Upgraded support facilities, such as an equipment storage building, a soil storage shelter, improved access roads, etc., are more likely to be constructed for a permanent site.

In most cases, a temporary biopile facility will be sufficient. However, in situations where the projected facility operating life is 5 or more years, a permanent biopile facility would be warranted. Other site-specific requirements, such as directives from command authorities or an expected high soil throughput, may dictate the selection of a permanent biopile. Sites expecting to handle soils from several locations in batches over extended time periods may consider the cost-to-benefit ratio of a permanent versus temporary facility.

The lower cost and the reduced site closeout and permitting requirements of a temporary biopile site usually will compare favorably to the more involved site development and higher capital costs of a permanent facility. Where useful, the project officer may decide to incorporate some of the support features of a permanent site, such as an equipment storage building or an improved surface for material processing, without choosing a concrete pad.

5.3 Biopile Site Selection . The biopile site, whether temporary or permanent, must be accessible, have access to utilities, be flat on solid ground, be located beyond the 100-year flood plain, be securable, and not be within a residential area. Selecting a site that has existing facilities can reduce costs and site preparation time. Useful amenities could include a usable asphalt or concrete pad (such as a parking lot), covered area for soil and equipment storage, utilities, and a secured perimeter. Table 2 lists suggested guidelines for selecting a biopile site.

Early in the site selection process, the project manager should ask base authorities for suggestions on where to locate the biopile facility. Regulatory officials also may have constructive input in the site selection process. Receiving timely guidance could reduce the risk in choosing a location. After deciding on a potential location, a site walkthrough should be organized to include staff from the base facilities and environmental departments. During the walkthrough, available utilities and other amenities can be identified, and shortcomings and possible upgrades can be noted. The walkthrough also can assist the project officer to develop a tentative site layout that can be presented in the work plan to base and regulatory officials. Once final approval has been granted, the work plan can be finalized and site preparation can begin.

When choosing a site, consider the following points as part of the selection process:

- Choose a centralized site for soil handling.
- Avoid off-base soil hauling, because it is hard to get public approval for a truck route.

- Choosing a site with a slight slope is acceptable, because this may be desirable for biopile drainage.

Table 2. Biopile Site Selection Guidelines

Selection Parameter	Definition	Recommendation
Geography	Location and natural and improved site conditions	Select a flat area with good drainage located outside the 100-year floodplain. Site should be located a reasonable distance (~500+ yd) from residential areas. Existing improved site, such as a parking lot or vacant storage yard, would be attractive.
Accessibility	Approach to and exit from site	Roadway(s) to site should be improved gravel, asphalt, or concrete. Hard dirt may be acceptable in arid climates. Ensure load limits at bridges meet hauler's requirements. Locate site close to contaminated soil source, if possible. Ensure site will be available for duration of project.
Space requirements	Area required to operate biopile facility	Includes access/egress road, soil storage area, processing area, biopile, pump shed, storage tank, and buffer zone.
Utilities	Electricity and water sources	For single biopile pad, 110/220-V, 60-amp lines should be sufficient. Check with electrical shop for actual requirements. Water source should be present on site.
Soil logistics	Transport, handling, storage of soil	Delivery trucks need adequate access route and space to maneuver on site. Soil handling equipment should be available for any required moving, mixing, and shredding of soil. Contaminated soil area must have an impermeable, bermed liner pad. Stored soil should be protected from the weather using a waterproof cover, or by placing soil under a roof.
Security	Site access control measures	Fenced-in area with gated access. Place sign at gate citing project type and point of contact. Lock storage and pump house.

- Choosing a site with nearby sources of power and water is very desirable.

5.4 Sizing the Site. The quantity of contaminated soil to be received, frequency of reception, expected retention time in the biopile, and soil preparation requirements will dictate the area required for storage and treatment. The site geography and existing facilities, such as buildings, pavement, fencing, etc., must be taken into account along with the net storage and treatment areas required to calculate the area and map the overall site boundaries.

For a 500-yd^3 (382-m^3) biopile system, the net treatment area will consist of the 50 ft × 60 ft (15.2 m × 18.3 m) biopile pad; the associated footprints of the pump shed, leachate collection tank, and off-gas treatment unit; the soil storage area; space to maneuver soil-handling equipment; and space to prepare the soil (if needed). The 50 ft × 60 ft (15.2 m × 18.3 m) biopile cell can process a soil volume ranging from 250 to 750 yd^3 (191 to 573 m^3), with 500 yd^3 (382 m^3) being the median design volume. The typical pump shed is 8 ft × 10 ft. The soil storage pad could feasibly be smaller than the biopile pad, because the soil can be stacked higher on the storage pad. An estimated soil storage area with a 500-yd^3 (382-m^3) capacity would be 1,700 ft^2 (158 m^2), assuming a 10-ft (3-m) height. Figure 10 depicts a biopile system with a 500-yd^3 median capacity.

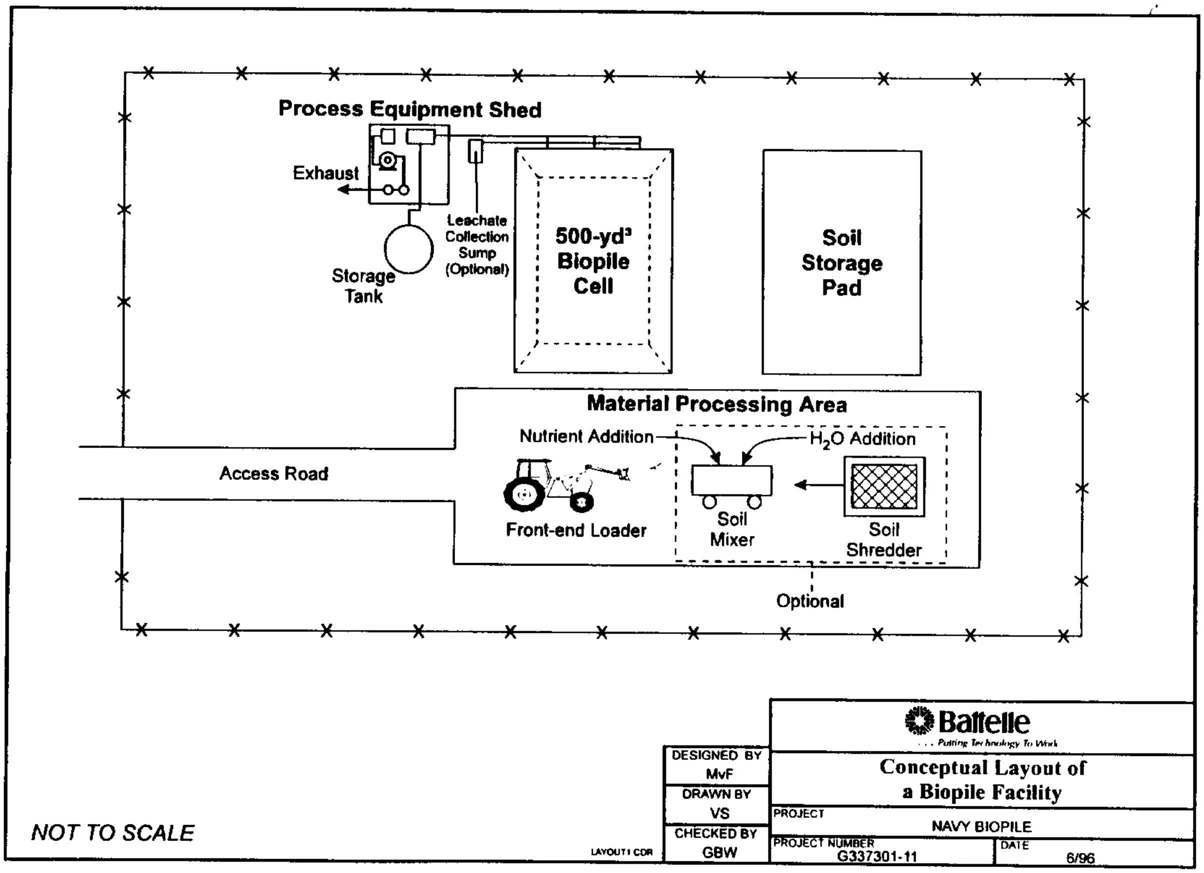


Figure 10. Plan View of a Biopile Site Layout.

Taking into account the net treatment and storage space requirements, an estimated size for a 500-yd^3 (382-m^3) biopile facility would be 11,000 ft^2 (1,022 m^2), plus an access road. As shown in Figure 11, facilities having more than one 500-yd^3 (382-m^3) module could use a shared soil processing area. Assuming a common soil staging and processing area and overlapping space for equipment maneuvering, a 3,000-yd^3 (2,294-m^3) biopile facility would require a minimum of 40,000 ft^2 (3,716 m^2) for the entire site. At some sites, the existing fixed facilities or geography may add to the total site size. For permanent biopile facilities, additional space would be needed to erect additional buildings, for example, to serve as a control center or to store equipment.

The BPCE is based on the designs presented in this manual and takes into account installation and operating requirements. Operating requirements include weekly and monthly services, sampling and analysis, rebuilding of the biopile when multiple cycles are required, and site closeout costs. Design assumptions made in the BPCE to estimate the treatment cost per cubic yard are as follows:

- Land is available at no cost.
- A sufficient soil storage area already exists.
- Permitting has been completed.
- Soil is transported to and from site at no cost.
- Utilities are provided at no cost.
- No contingency is made for replacement parts.
- No soil shredding or bulking agent addition is required.
- Labor rates include all applied overhead costs.
- The treatment cell dimensions are 50 ft × 60 ft (15.2 m × 18.3 m) with a mean treatment capacity of 500 yd^3 (382 m^3) and a maximum soil capacity of 750 yd^3 (573 m^3).
- The aeration system operates in the extraction mode with off-gas treatment.
- No irrigation system is required.
- 2,900 lb (1,315 kg) of urea and 400 lb (181 kg) of diammonium phosphate are added per cell as nutrients.
- The processing time per cycle is 4 months.

In general, the cost to treat a unit volume of soil will decrease as the number of treatment cycles per cell increases. The cost of a permanent biopile facility generally begins to become comparable with respect to the cost of a temporary facility when the total soil volume to be treated exceeds 5,000 yd^3 (3,823 m^3). In general, a permanent facility should be considered if the expected project life is 5 years or more. However, site-specific conditions may dictate whether to use a temporary or permanent biopile design, irrespective of the expected total volume or project life.

Taking into account the net treatment and storage space requirements, an estimated size for a 500-yd^3 (382-m^3) biopile facility would be 11,000 ft^2 (1,022 m^2), plus an access road. As shown in Figure 11, facilities having more than one 500-yd^3 (382-m^3) module could use a shared soil processing area. Assuming a common soil staging and processing area and overlapping space for equipment maneuvering, a 3,000-yd^3 (2,294-m^3) biopile facility would require a minimum of 40,000 ft^2 (3,716 m^2) for the entire site. At some sites, the existing fixed facilities or geography may add to the total site size. For permanent biopile facilities, additional space would be needed to erect additional buildings, for example, to serve as a control center or to store equipment.

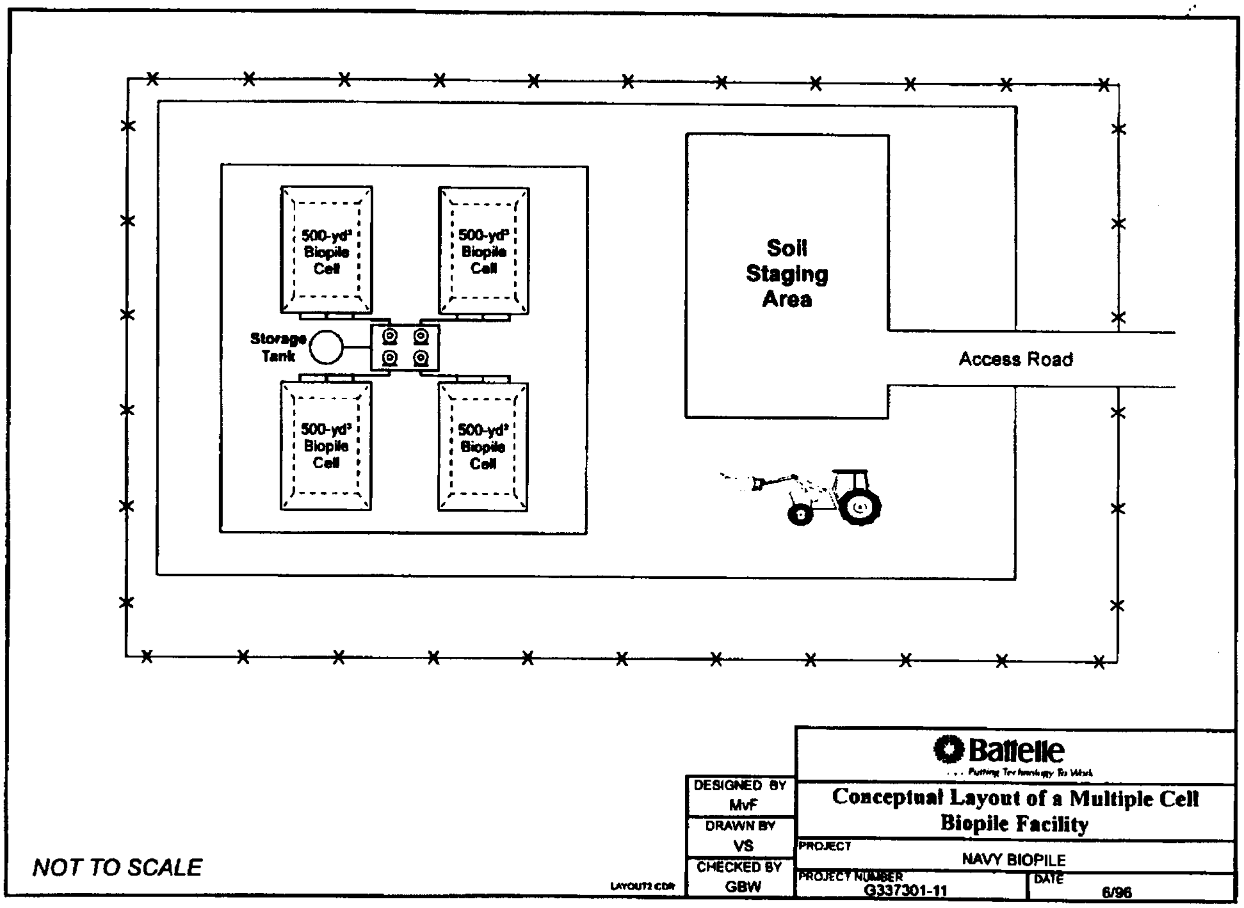


Figure 11. Plan View of a Site with Multiple Biopile Modules.

5.5 Cost Analysis. To provide the reader with an idea of the cost of a biopile system, various cost models were run using the Biopile Cost Estimator© (BPCE) software, Version 1.21, developed by Battelle for the Naval Facilities Engineering Service Center (NFESC, 1996a). The parameters and resultant costs for each case calculated are summarized in Table 3. Appendix H contains cost summary sheets for each case. Appendix H also gives examples of the detailed cost sheets for the installation and operation and maintenance cost estimates for the temporary and permanent baseline biopile cases treating a total of 500-yd^3 (382-m^3) of soil.

Table 3. Summary of the BPCE Cost Analyses for a Biopile Construction and Operation

Biopile Type	Total Volume (yd^3)	No. of Treatment Cells	Volume per Cell (yd^3)	No. of Cycles	Project Life (months)	Cost ($/yd^3)
Temporary	500	1	500	1	4	103.49
	1,000	1	500	2	8	75.58
	2,000	1	500	4	16	63.26
	2,000	2	500	2	8	69.70
	5,000	1	500	10	40	56.65
	5,000	1	750	7	28	40.71
	5,000	2	500	5	20	56.54
	5,000	2	750	4	16	46.26
Permanent	500	1	500	1	4	196.99
	5,000	1	500	10	40	66.30
	5,000	1	750	7	28	50.36
	10,000	1	500	20	80	61.47
	10,000	2	500	10	40	62.71
	20,000	2	500	20	80	58.27
	20,000	4	500	10	40	62.45
	40,000	4	750	14	56	41.34

Section 6.0: BIOPILE CONSTRUCTION

In Section 2.0, a general biopile technical overview is presented. This section is focused on specific biopile design. Section 6.1 describes the construction of a temporary biopile. Section 6.2 describes additional design considerations for building a permanent biopile.

The baseline biopile design presented herein has been sized to accommodate 500 yd^3 (382 m^3) of contaminated soil. This size is sufficient to handle contaminated soil generated from most UST excavations. Additional biopile pads can be constructed to handle larger volumes. Although multiple cells can require somewhat more space than a single, large cell, the modular approach has several advantages. This approach enables better soil management with respect to receipt, storage, handling, and amendment of soils. Having more than one biopile pad enables the site manager to process soils in smaller, discrete batches. Furthermore, if one shipment of soil is exceptionally difficult to treat, due to the level of contamination or other reason, it would be isolated from the rest of the soils being processed.

The 500-yd^3 (382-m^3) size is large enough to process a significant volume of soil, yet small enough to allow two workers to apply and remove the biopile cover. With larger piles, the plastic cover becomes difficult to install and remove when conducting either moisture addition or soil sampling. Another advantage of a biopile limited to approximately 500 yd^3 (382 m^3) is that a smaller pile is easier to aerate evenly than a larger pile.

The phases involved in constructing a biopile include:

- site preparation
- base construction
- aeration system installation
- nutrient addition
- moisture addition system
- leachate collection system installation (optional)
- pile formation.

Each of these phases is described in Section 6.1. Design considerations for permanent biopile sites are covered in Section 6.2.

6.1 Temporary Biopile Construction. Once the biopile site has been selected and the proper permits have been obtained, the biopile construction can begin. The number of biopile pads and the size of the soil storage area need to be calculated based on the volume of soil to be treated at the site per 3- to 6-month period. Figure 12 is a general checklist that summarizes the major biopile construction activities. Figure 13 is an example list of parts needed for building one 500-yd^3 (382-m^3) temporary biopile module.

BIOPILE CONSTRUCTION CHECKLIST

Order materials ___
Construct:
    soil storage pad foundation ___
    soil storage pad ___
    biopile pad foundation ___
    biopile pad ___
    pump pad / shelter ___
    water knockout system ___
    off-gas treatment system ___
    aeration system ___
    irrigation system (optional) ___
    leachate collection system (optional) ___
Ensure power and control circuits are installed properly ___
Form biopile ___
Install cover ___
Receive and cover contaminated soil on storage pad or place directly on biopile pad if it is completed ___
Construction requirements:
    minimum two laborers and one front-end loader operator ___
    minimum heavy equipment: one front-end loader ___
additional soil blending equipment (optional) ___
water source ___
nutrients ___
health and safety equipment as dictated in the Health and Safety Plan ___
Conduct time-zero sampling ___

See parts list in Figure 13 for related materials and equipment.

Figure 12. Biopile Construction Checklist

EXAMPLE PARTS LIST

treated 4-inch × 4-inch lumber
treated 2-inch × 4-inch lumber
3/4-inch × 6-inch lag bolt w/washer and nut to secure 4-inch × 4-inch beams
connecting brackets to join 4-inch × 4-inch beams
60-mil (or thicker) 51-ft × 61-ft HDPE bottom liner
3/8-inch × 3-inch hex head sheet screw w/washer @ 100 ea.

clean dirt or clay for 8-inch foundation @ 71 yd^{3}
4-inch flexible, slotted drainage pipe @ 90 ft
4-inch end caps for drainage pipe @ 3 ea.
4-inch schedule 40 PVC pipe @ 30 ft
4-inch rubber unions to connect drainage pipe to PVC @ 3 ea.
4-inch brass gate valves @ 3 ea.
4-inch schedule 40 PVC threaded/slip coupling @ 6 ea.
4-inch to 2-inch PVC reducing bushing @ 3 ea.
2-inch PVC slip tee @ 2 ea.
2-inch PVC slip elbow @ 2 ea. (will vary depending on site layout)
2-inch schedule 40 PVC pipe @ 60 to 80 ft (adjust as dictated by proximity of pump)
5-gal water knockout tank with automatic level control
1-inch schedule 40 PVC pipe @ 20 to 40 ft (adjust as required to plumb from knockout tank to water collection tank)
miscellaneous 1-inch PVC fittings as required
500-gal water collection tank
1½-hp rotary positive displacement vacuum pump @ 1 ea.
concrete pad or other solid base for pump foundation
storage shed to house pump and materials
55-gal granular activated carbon drum @ 2 ea.
miscellaneous PVC fittings to connect knockout tank, pump and carbon drums
plastic sheeting (HDPE or qualified substitute) to serve as top cover @ 75 × 75 ft
2-inch × 4-inch × 6-ft treated wood slat for securing cover @ 30 ea.
5/16-inch × 4-inch hex head sheet metal screw @ 100 ea.
nylon rope @ 400 ft
5/16-inch × 3-inch eye-screw @ 12 ea.
nutrients (e.g., urea and diammonium phosphate or calcium phosphate) to achieve 100:15:1 carbon-to-nitrogen-to-phosphorus ratio
water hoses with nozzles
scoop for nutrient addition
scale to measure nutrients (optional)
1-gal bucket for holding/distributing nutrients (optional)
¼-inch nylon tubing for monitoring points
    green @ 100 ft; red @ 300 ft; blue @ 300 ft
monitoring point screen @ 10 ea.
¼-inch brass quick-disconnect coupling set for monitoring points @ 13 ea.
thermocouple wire w/plug, 40-ft length @ 2 ea.
K-type thermocouple wire w/plug, 20-ft length @ 2 ea.
shovel @ 2 ea.
health and safety equipment as specified in the health and safety plan
duct tape @ 1 roll

Figure 13. Example Parts List.

6.1.1 Site Preparation. The first step in site preparation is to evaluate the site with respect to material flow, access to utilities, site entrance and exit, existing security measures, and general layout of space (Figure 14). For the standard 500-yd^3 (382-m^3) module, the dimensions of the biopile pad will be 50 ft × 60 ft (15.2 m × 18.3 m) with a pile height ranging from 5 to 6 ft (1.5 m to 1.8 m). The storage pad dimensions can vary according to site limitations and the actual soil volume to be treated.

SITE PREPARATION ACTIVITIES

- Develop a site preparation and construction schedule.
- Prepare Health and Safety Plan and obtain required approvals.
- Coordinate with base environmental and facilities staff to establish construction start date and vase support and to determine what facilities are available.
- Conduct a walk through survey of site with base facilities representative to visually identify site assets, space, and deficiencies.
- Contact electrician to install/modify electrical power as necessary.
- Have base facilities support install waterline with spigot, if one is not available.
- Clear debris in and around site.
- Install security measures, such as a fence with gated access and appropriate signs.
- Grade area for soil storage pad and biopile pad(s).
- Set up soil processing equipment if soil will need screening, blending, or shredding.

Figure 14. Site Preparation Checklist.

For example, sites with total soil volumes of less than 500 yd^3 (382 m^3) would require a slightly smaller pad. Sites with a total volume between 500 and 750 yd^3 (382 m^3 and 573 m^3) could use the same base pad dimensions but would be higher (up to 8 ft [2.4 m]).

When laying out the site, the movement requirements of trucks hauling soil, the front-end loader, and any mixing equipment need to be considered. If the treatability study indicated the need for soil shredding, bulking agent addition, or soil mixing, an area to accommodate the required equipment and material processing also should be identified.

Before construction of the storage and biopile pads can begin, the site is cleared of brush, debris, and other obstacles. If the site contains an existing improved surface, such as an asphalt or concrete area, this surface can be used as the foundation for the staging area, and for the storage and biopile pads. If there is no improved surface, the foundations for the soil storage area and the biopile need to be constructed by grading and compacting clean soil or clay.

As soon as the site has been identified, the site manager should arrange for installation of power and water utilities if they are not already in place. The electrical power input must be sufficient to service the required blower(s). For a single 500-yd^3 (382-m^3) biopile, a 110/220-V, 60-amp, single-phase circuit to power a 1½-hp (1,120-W) blower will be sufficient. Additional blowers would require an increase in the voltage or amperage requirements. The local electrical support shop or contractor will be able to recommend the exact power needs for the site. Additionally, a 110-V single-phase line should be in place to power the sump pump from the leachate collection tank and the aeration line water knockout tank pump. Miscellaneous control units, recorders, and remote sampling and data acquisition units may need a 110-V power source. Water will be required at the site to hydrate the soil.

6.1.2 Biopile Base Construction. The biopile base consists of a soil or clay foundation, impermeable liner, leachate containment berm, and clean soil base. The optimal thickness of the soil or clay foundation ranges from 6 to 10 inches (15.2 to 25.4 cm) of loose soil that should be compacted to between 80 and 85%. Where possible, an existing asphalt or concrete surface, such as a parking lot, can serve as the biopile and storage area foundations, in lieu of the compacted soil or clay. Ideally, the graded foundations for the storage area and the biopile should be smooth with approximately a 1- to 2-degree slope toward the leachate collection drain line or sump located at one corner of the biopile. The foundation should extend approximately 3 ft (0.9 m) beyond the biopile base to allow for the emplacement of the aeration manifold header, any irrigation lines, and the biopile berm.

Once the foundation has been selected and formed, the impermeable liner is placed over the base. The liner typically is a thick plastic material such as 40- to 60-mil high-density polyethylene (HDPE). The liner must be large enough to cover the desired 50 × 60 ft (15.2 × 18.3 m) base and to enable secure attachment to the side or top of the biopile berm. The liner can be fastened to the berm using lag screws with washers. Figure 15 outlines the construction design of a typical temporary biopile; Figure 16 shows a plan view of the biopile construction.

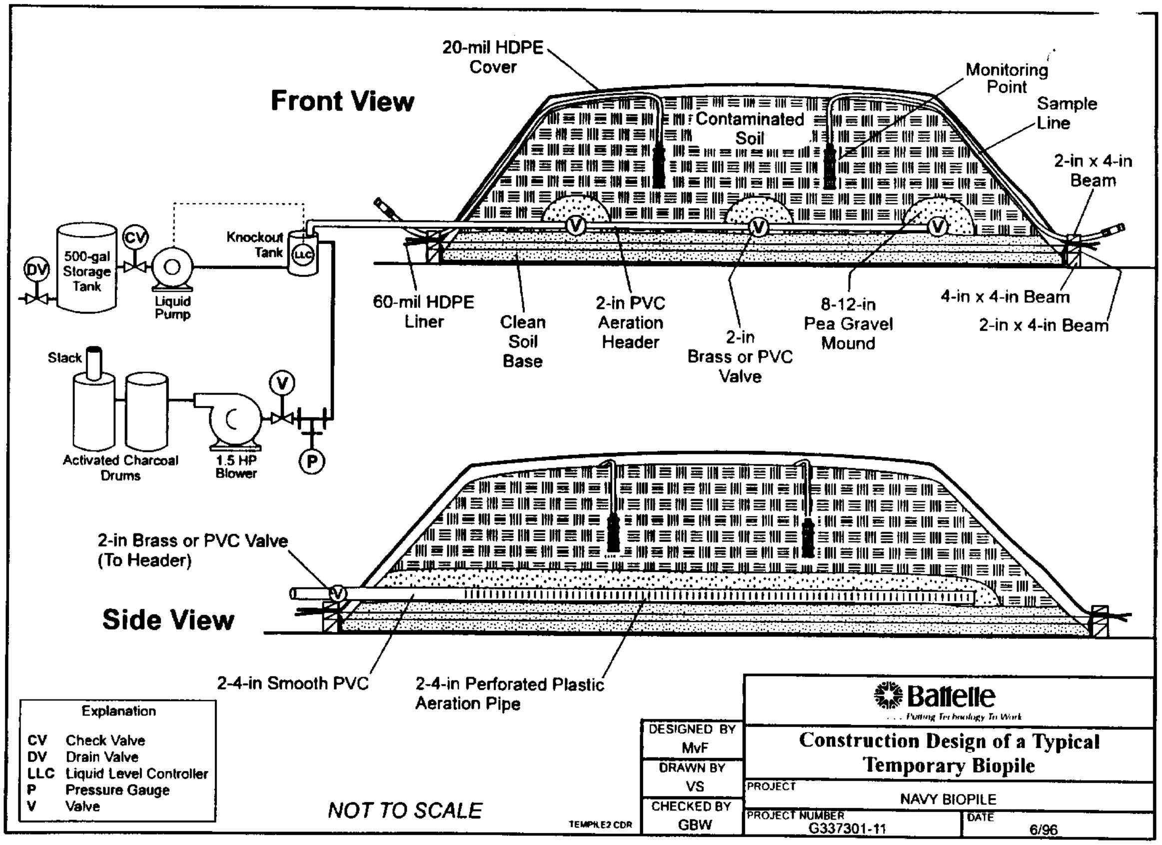


Figure 15. Construction Design of a Typical Temporary Biopile.

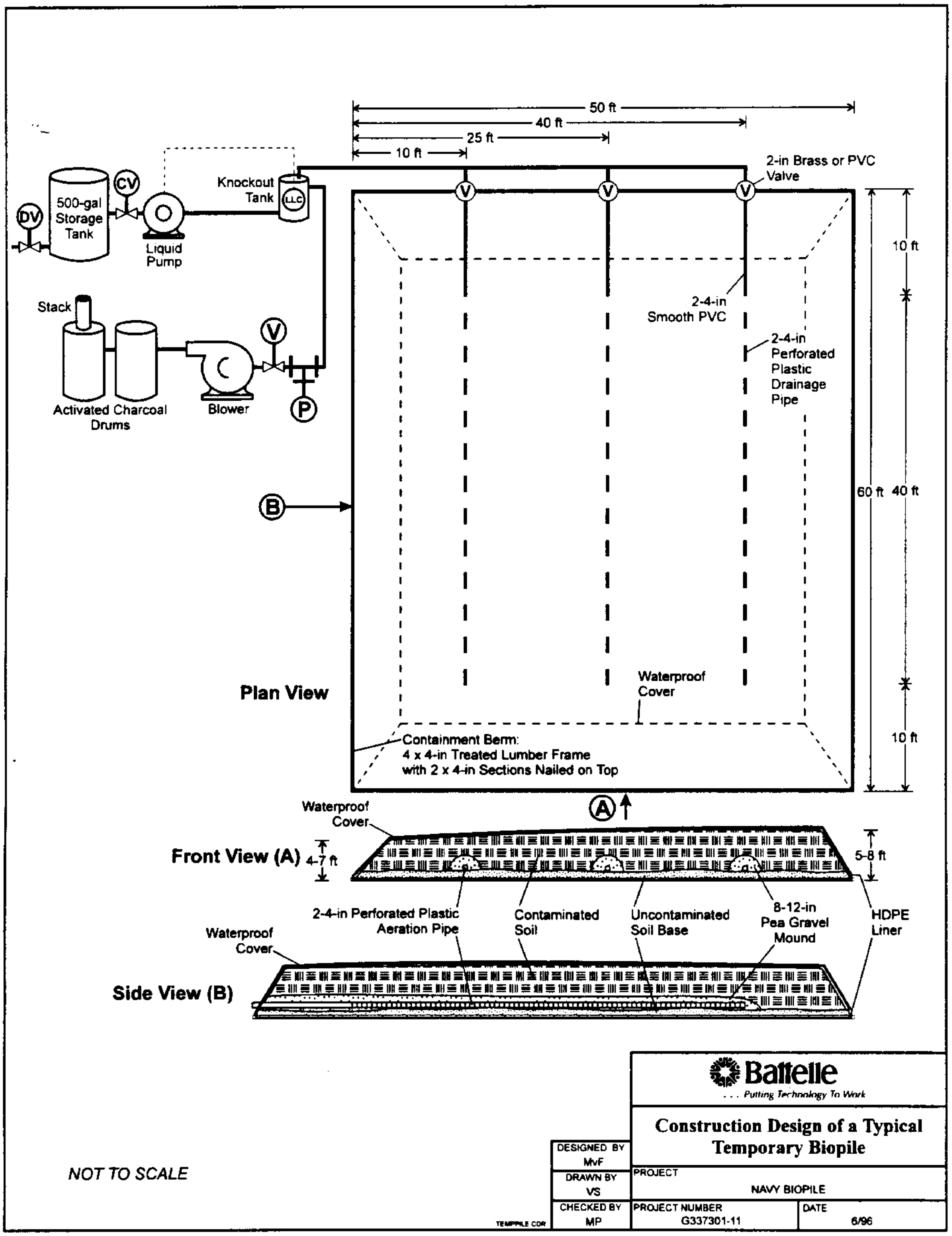


Figure 16. Construction Design Detail of a Temporary Biopile.

The leachate containment berm framing the biopile liner can be constructed using one layer of treated wood 4-inch × 4-inch beams topped with a layer of treated wood 2-inch × 4-inch or a second layer of 4-inch × 4-inch beams. The 4-inch × 4-inch beam sections can be joined using metal brackets and hex head lag screws. The second layer of wood can be connected to the bottom layer with either brackets or by drilling screws directly into the bottom layer. When constructing the berm, it may be useful not to attach the side opposite the aeration manifold header to the other two berm sides, so that it can be removed during the construction of the biopile. Having the side opposite the manifold header relatively flush with the foundation will enable easy access to the biopile base with the front end loader as it transports clean soil for the soil base construction and contaminated soil from the storage area for the pile construction. Temporarily removing the one berm side will eliminate the necessity and effort of building and removing a soil ramp for the loader to drive onto the biopile base pad. Once all the soil has been loaded on the biopile pad, the removed berm wall can be replaced and secured.

After the liner and berm have been emplaced, the 8- to 10-in. (20.3- to 25.4-cm) clean soil base can be placed over the liner. The clean soil base serves to protect the liner during the biopile construction and removal. The clean soil base should be compacted to prevent short-circuiting of the air flow.

6.1.3 Aeration System. Air can be pushed or pulled through the biopile with a blower. Injecting (pushing) air is preferred, because the blower does not need to be preceded by a water knockout system to protect it from exhaust gas condensate and possible biopile leachate. However, in cases where exhaust gas treatment or a leachate collection system is required, the aeration system will need to operate in the extraction mode.

The basic aeration system components are an aeration pump, an air manifold with a header pipe connected to the pump, and valves at the manifold branch points. When operating in the extraction mode, a water knockout tank, cyclone separator (optional), knockout water collection tank, and exhaust gas treatment unit (optional) are added to the aeration system.

The aeration pipes are placed on the clean soil base and lead back to the manifold header. Each aeration leg is joined to the manifold header via a gate valve. The valve is used to adjust the airflow through each leg. The header pipe leads to a water knockout tank to separate the bulk of the water carried through the header from the biopile. Water from the knockout tank can be pumped to a 500-gal (1,895-L) water collection tank, which can be the same as the leachate collection tank, if one is used (see Section 6.1.6). Following the water knockout tank, a cyclone separator can be installed, if deemed necessary, to remove remaining moisture droplets still entrained in the biopile exhaust. Removing water droplets from the exhaust gas is important when a carbon absorption unit is used to treat volatile organic carbon (VOC) emissions and helps to protect the blower. Although a relative humidity (rH) of up to 90% will not be detrimental (75% max. rH is ideal), free water droplets can cause the activated carbon to lose effectiveness as it becomes saturated with water. The activated carbon canister size can be obtained from a vendor of activated carbon.

If during the initial feasibility analysis and permitting process exhaust gas treatment was deemed necessary, two activated carbon canisters can be installed in series to remove VOCs. Duplicate carbon canisters are installed to ensure continued off-gas treatment should the first canister reach the contaminant breakthrough stage. To monitor the continued efficacy of the off-gas treatment unit, a sampling port can be installed between the two canisters for periodic off-gas monitoring. If off-gas treatment is not necessary, the aeration system can be run in the extraction mode without carbon canisters, or it can be run in the injection mode. If run in the injection mode, the knockout tank, water collection tank, and off-gas treatment system are not needed. When running in the injection mode, extra caution must be taken to ensure the cover is properly secured.

Each 2- to 4-inch (5.1- to 10.2-cm)-diameter aeration leg should be constructed from one 10-ft (3-m)-long section of blank PVC pipe and one 30-ft (9-m)-long section of slotted, corrugated, and flexible drainage pipe or slotted PVC. The drainage pipe is capped at the end. A rubber union can join the flexible pipe to the PVC pipe. The PVC pipe is connected to the 2-inch (5.1-cm) valve that leads to the 2-inch (5.1-cm) manifold header pipe. The distance between aeration pipes should be 8 to 10 ft (2.4 to 3.0 m). To prevent short-circuiting of the airflow through the pile, the slotted portions of the aeration legs should be placed toward the center of the pile (i.e., the connection between the blank and the slotted pipe should be approximately 10 ft (3 m) from the biopile berm). Figure 17 shows a schematic of the aeration system configured to operate in the extraction mode.

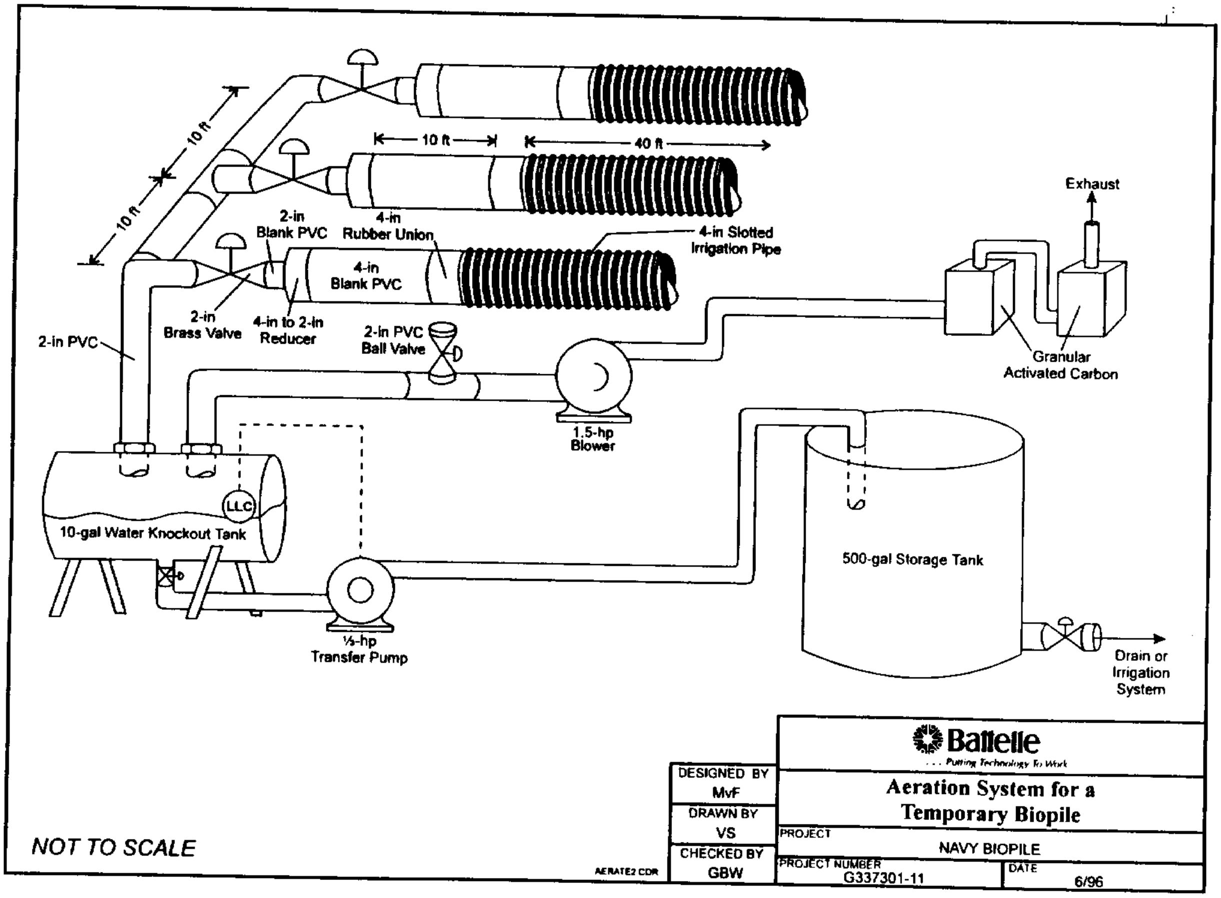


Figure 17. Aeration System for a Temporary Biopile Configured
to Operate in the Extraction Mode.

The aeration source that either pushes or pulls air through the pile should be a 1½-hp regenerative centrifugal (preferred) or rotary positive-displacement blower capable of drawing approximately 120 scfm (3,400 sLm). The blower should be placed on an improved, level surface, preferably a concrete pad. Power requirements for the blower, generally single-phase 110/220-V, will be specified by the vendor and in the blower installation manual. A tee fitting with a ball valve attached to the unconnected end should be installed just prior to the blower inlet. The valve can be used to regulate airflow through the pile (Figure 17). Housing the pump in a shed will protect it from the weather. The same shed can serve as a storage area for materials.

6.1.4 Nutrient Addition. Nutrients (nitrogen, phosphorus, potassium) are sold as commercial fertilizer in bag or bulk form. Nutrients can be added by dissolving them in water and spraying the nutrient solution into the soil during the mixing process, or they can be added as dry powder or granules. If no soil mixing is conducted, nutrients can be added as the soil pile is formed. When adding nutrients to the pile as a solution in water, care must be taken that the nutrient solution soaks into the soil and does not leave the soil as runoff. For soils that are not absorbent or that form a crust when wetted, dry nutrient addition during pile formation may be more effective.

Nutrient addition should be controlled by calculating the nutrient requirements and applying the nutrients at a known rate to the soil being piled on the biopile pad. Figure 18 shows a nutrient addition calculation worksheet that can be used to determine the amount of nutrients to add per quantity of soil (in this illustration pounds of nutrient per cubic yard of soil). Appendix J gives a detailed sample calculation for nutrient addition requirements.

When applying nutrients as a solution, the application rate can be regulated by knowing the nutrient concentration levels in the solution, the solution flowrate, and the volumetric application rate of the soil by the loader. The nutrient solution can be formed in the leachate collection tank and applied using a sump pump and garden hose. The flowrate can be calculated by timing how long it takes to fill a 5-gal (19 L) bucket with the nutrient solution. The soil application rate is merely the number of buckets the loader applies to the pile per unit time.

When applying dry nutrients to the soil, they can be weighed in a bucket and applied to the proper amount of soil. An easy way to apply dry nutrients is to measure the amount required per bucket and add that amount with each scoopful of soil.

6.1.5 Moisture Addition. Having a sufficient moisture content in the pile, generally 70 to 95% of field capacity, is one of the critical factors for successful contaminant biodegradation. In moderate climates, a biopile generally loses 1 to 2 weight % of the original water. Therefore, if the biopile is sufficiently hydrated when the pile is constructed, no irrigation system usually will be required. The water can be added in three ways:

- Hydrate the soil while it is still on the storage pad.
- Add water as the pile is being constructed.
- Install a dripline irrigation system across the top of the pile.

BIOPILE NUTRIENT ADDITION WORKSHEET

1. Nutrient Source:
   a. Nitrogen source (e.g. urea) ________ ________ weight fraction nitrogen (urea = 0.46)(a)
   b. Phosphorus source (e.g. diammonium phosphate) ________ ________ weight fraction phosphorus
   c. Potassium source (e.g. potassium sulfate) ________ ________ weight fraction potassium

2. Total organic carbon content in soil: ________ mg / kg dry soil. Obtained from laboratory results. If unknown, calculate as below:
   a. Average concentration of hydrocarbon contamination in soil = ________ mg / kg dry soil
   b. Average carbon content in contamination = line 2a × 0.8 = ________ mg carbon / kg dry soil

3. Desired C:N:P:K ratio. Determine by treatability tests, else use C:N:P:K = 100:15:1:1.

4. Amount of nutrient to add per kg of dry soil. (If not known, assume negligible N,P,K content in soil prior to nutrient addition.)
   a. Nitrogen (N) needed to be added per kg dry soil = line 2b. × 0.15 = ________ mg N / kg soil
   b. Phosphorus (P) needed to be added per kg dry soil = line 2b. × 0.01 = ________ mg P / kg soil
   c. Potassium (K) needed to be added per kg dry soil = line 2b. × 0.01 = ________ mg K / kg soil

5. Bulk density of soil = ________ kg / m^3.[b] (Assume 1,400 kg / m^3 if unknown.)

6. Nutrients required per m^3 of soil:
   a. kg N / m^3 soil = line 4a. × line 5 ÷ 1,000,000 = ________ kg N / m^3 soil
   b. kg P / m^3 soil = line 4b. × line 5 ÷ 1,000,000 = ________ kg P / m^3 soil
   c. kg K / m^3 soil = line 4c. × line 5 ÷ 1,000,000 = ________ kg K / m^3 soil

7. Pounds of nutrients required per cubic yards of soil
   a. lb N / yd^3 soil = line 6a. × 1.69 = ________ lb N / yd^3 soil
   b. lb P / yd^3 soil = line 6b. × 1.69 = ________ lb P / yd^3 soil
   c. lb K / yd^3 soil = line 6c. × 1.69 = ________ lb K / yd^3 soil

8. Total volume of soil to be treated by biopile: ________ yd^3

9. Pounds of nutrient source to be added per cubic yard of soil:
   line 7a. ÷ line 1a. = ________ lb of N source required / yd^3 soil
   line 7b. ÷ line 1b. = ________ lb of P source required / yd^3 soil
   line 7c. ÷ line 1c. = ________ lb of K source required / yd^3 soil

10. Total pounds of nutrient sources required for the biopile:
    line 9a. × line 8 = ________ lb of N source(c) to be purchased
    line 9b. × line 8 = ________ lb of P source to be purchased
    line 9c. × line 8 = ________ lb of K source to be purchased

(a) Weight fraction = % ÷ 100.
(b) 1 kg / m^3 = 1.688 lb / yd^3.
(c) Assumes all N comes from a single source.
NA = not applicable.

Figure 18. Biopile Nutrient Addition Worksheet.

While the soil is still on the storage pad, it can be hydrated using a hose and a sprinkler or by digging holes partially into the pile with a hand auger and filling the holes up with water. Irrigating the pile from the top with a sprinkler may cause excessive runoff if the soil crusts over or is too tight to rapidly absorb the water. Water added in hand-augured holes will drain through the soil to achieve more thorough hydration than achieved by top irrigation.

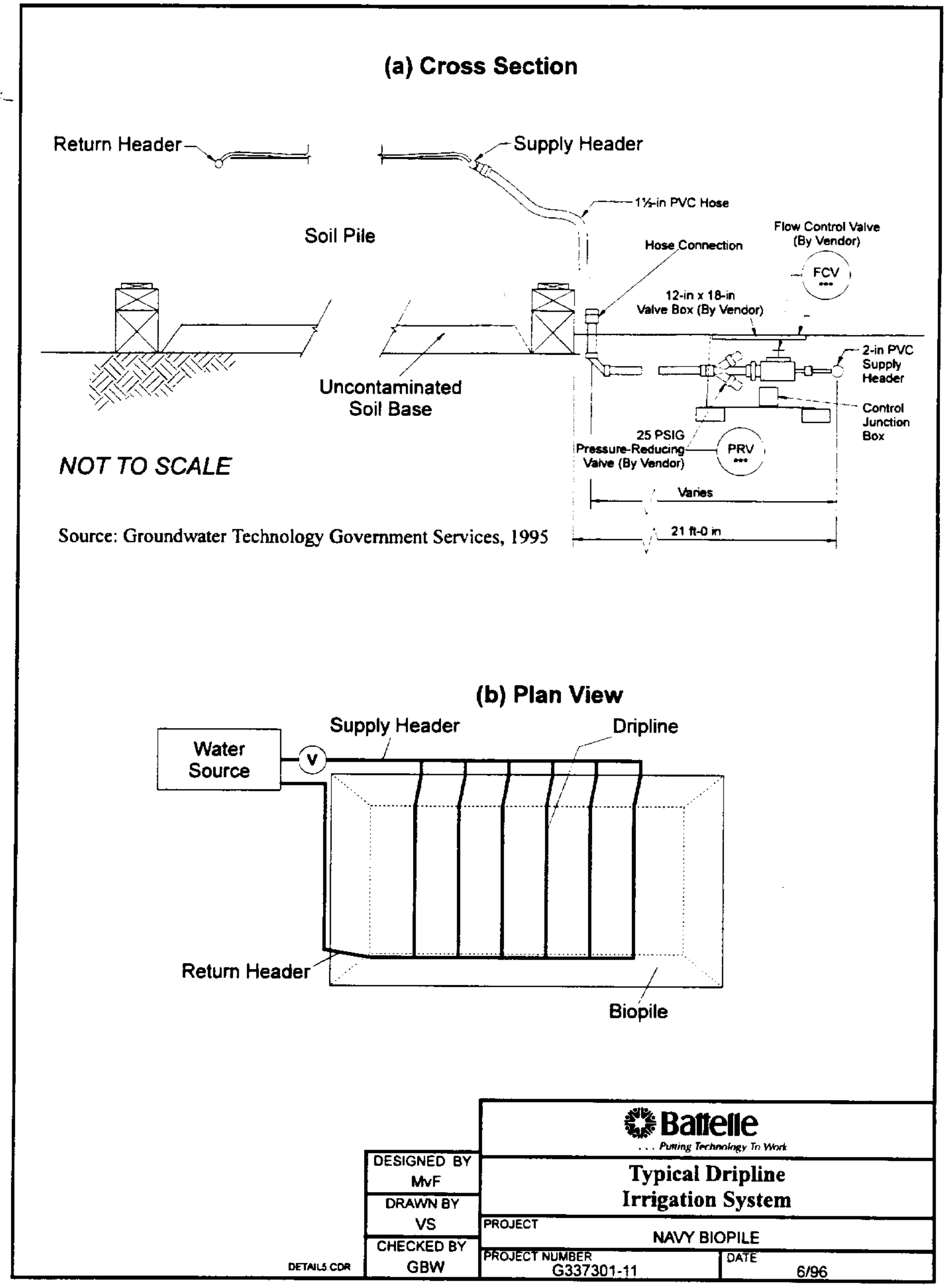
Adding water as the pile is being constructed may or may not be an effective method. If the soil is being shredded or blended, a precise amount of water can be added per batch of soil processed. However, if the soil is being piled rapidly onto the pad, the amount of water that can be added between loader buckets will provide only a fraction of the total water needed. Nevertheless, spraying water onto the soil as it leaves the bucket does add an appreciable amount of water evenly to the soil at all pile depths.

The amount of water to add can be calculated by knowing the moisture content of the soil before construction, the flowrate of water from the water hose, and the volume of soil contained in one loader bucket. The amount of time water needs to be added per bucket is equal to the water needed per bucket of soil divided by the total water flowrate. The water flowrate from the hose can be calculated by timing how long it takes to fill a 5-gal (19-L) bucket with water. Dividing that time by 5 gives the water flowrate in gallons per minute (gpm).

Initial soil samples will have been collected and analyzed by a laboratory for several variables, including moisture content. However, the actual variable needed to construct the biopile is the percent of water-holding field capacity to which the soil is hydrated. The desired value is 70 to 95% of field capacity. The field capacity can be determined in the laboratory using ASTM D2365 or ASTM 3152. Methods for estimating the field capacity of a soil are shown in Appendix G.

At most sites, it may not be necessary to hydrate the pile following initial water addition. After completion of construction, if needed, water can be added via a dripline irrigation system (Figure 19). The dripline system applies water at a low rate to prevent the formation of water pools and the subsequent runoff that would result from using higher flowrates. The dripline can be designed so that water is dispersed uniformly across the biopile surface. The water flowrate through the dripline system can be measured with a simple rotameter. Once the desired amount of water has been added to the biopile, the dripline can be turned off. The dripline system has three advantages:

- It is a convenient and effective method to add water to the biopile after the pile has been covered.
- The low water flowrate minimizes water runoff from pile.
- The system can operate without supervision.
- Irrigation by this method can achieve even water distribution.



Source: Groundwater Technology Government Services, 1995

Figure 19. Typical Dripline Irrigation System

The dripline irrigation system has three disadvantages:

- The initial cost is a factor not required by other types of irrigation.
- Some installation time is required.
- The dripline may break and spring a leak to cause excess leachate.

6.1.6 Leachate Collection System. The biopile configuration featured in this document is designed to minimize the formation of leachate. Therefore, unless mandated by special circumstances or regulations, the construction of a leachate collection system should not be necessary, because the bermed liner is designed to contain any water or leachate that migrates to the bottom of the pile. However, if a leachate collection system is warranted, it should be constructed by sloping the biopile base toward one corner of the pile to channel any leachate to a leachate collection pipe or preferably by incorporating the leachate collection with the aeration system, as shown in Figure 3.

If a separate collection pipe is used, it should be a 2-inch (5.1-cm)-diameter slotted PVC pipe connected to a blank 2-inch (5.1-cm)-diameter PVC pipe that leads to a leachate collection sump or tank. If a leachate collection sump is used, it must be located below the grade of the biopile foundation and must be lined with an impermeable layer, such as a plastic tank.

If an aboveground leachate collection tank is used, it should be located within a secondary containment area, such as a lined berm and foundation that are large enough to contain the volume of the tank. A pump would be required to transfer the leachate from the collection pipe to the aboveground storage tank. The tank size can range from 500 to 1,500 gal (1,895 to 5,685 L).

One example where a leachate collection system may be warranted is in locations having strong winds. An exceptionally strong or persistent wind potentially may damage the biopile cover so that rainwater could saturate the pile and leach through it. If a leachate collection pump is used, a liquid level controller (LLC), such as a float switch, may be useful to turn the pump on and off as leachate collects and is removed from the leachate collection point. When a leachate collection system and a biopile irrigation system are both installed, the leachate can be recycled back to the pile through the irrigation lines.

6.1.7 Biopile Formation.

6.1.7.1 Soil Preparation. Contaminated soil is either loaded onto the biopile pad or preprocessed prior to forming the biopile. The initial soil characterization data that are required for selecting the biopile technology provides information for identifying the need for soil blending or shredding. These data include the particle size, clay and silt content, and void volume. The soil preprocessing can involve screening bulk objects, such as large rocks, followed by soil shredding and/or soil blending with a bulking agent. The extent of preprocessing required is a function of the soil type, soil composi-tion, and contamination level. For example, soils with low soil porosity (void volume <25%) could inhibit the airflow through the pile. Adding a bulking agent, such as rice hulls, shredded cardboard, or wood chips, would increase the void spaces in the amended soil matrix and thus improve the airflow through the pile. Generally, the soil needs to be screened prior to the soil shredding or blending step, to prevent damage to the shredding and mixing equipment. Typical soil processing equipment includes:

- bucket loader and/or skidsteer loader
- parallel bar screen to remove large, heavy objects
- trommel screen or vibrating screen for finer particle screening
- soil shredder
- a soil mixer, such as a KnightReelAuggie^{TM}, with a load cell for weighing and blending soil and amendments (including nutrients, bulking agent, and water).

Soil screening, shredding, and mixing equipment often can be rented or operated by a contractor. Soils not requiring shredding or blending may be applied to the biopile without a mechanical screening step. Some hand removal of large rocks or debris may be required in any case. For soil movement without screening or blending, the only equipment required is the bucket loader.

For cases where a soil mixer is employed, water and nutrients can be introduced into the mixer along with the soil. Nutrient addition is covered in Section 6.1.4, and Section 6.1.5 covers moisture addition.

6.1.7.2 Pile Formation. Following any soil preparation, the loader places soil on the biopile pad. The pile is formed by applying the soil in rows by working from “back to front,” starting at one side and moving to the other side as each row of soil fills the pad to the desired height of 5 to 8 ft (1.5 to 2.4 m). The “back” is the side where the aeration header is located. The “back” is also the side of the cell base that is opposite the side the loader enters. The term “front” refers to the side where the loader enters the biopile pad. The front-end loader must never be allowed to drive over previous lifts.

The loader must be careful not to drive over the aeration pipes as the pile is being formed. Also, to prevent damage to the containment berm, the side opposite the aeration manifold header can be removed to allow the loader to drive directly onto the clean soil foundation without driving over the berm. As an alternative, the loader can form a soil ramp to bridge the berm. For a permanent biopile cell, a ramp might be built. To form a relatively smooth heap, the loader operator should fill in and even out the rut between the rows as the pile is being constructed. The pile should have a relatively smooth top and a slight grade from one side to the other to prevent pooling of rainwater on the pile cover. Advising the loader operator in advance of the required configuration of the pile top will help to ensure the proper pile top finish.

When soil is applied to the biopile pad, have the loader operator leave a 1- to 2-ft (0.3 to 0.6-m)-wide space between the soil pile and the containment berm. This space will prevent soil from falling over the berm as the final pile height is reached, the pile top is graded by the loader, and water is added to the pile.

After the soil has been applied, the side of the berm removed earlier can be reinstalled or the soil ramp can be removed and added to the pile. The target biopile dimensions for a 500-yd^3 (382-m^3) system are 50 ft × 60 ft × 5 to 8 ft high (15.2 m × 18.3 m × 1.5 to 2.4 m high), with a pile slope of 1.25:1 side-to-height ratio. Figure 16 depicts the constructed pile dimensions.

6.1.7.3 Installing Soil Gas Monitoring Points Error! Bookmark not defined. Soil gas monitoring points are used to sample the biopile soil gas and can be installed as the pile is being formed. Data collected from the soil gas include oxygen, carbon dioxide, and TPH concentrations. A typical monitoring point construction is illustrated in Figure 20. Table 4 gives the monitoring point parts list and potential vendor sources.

The monitoring points can be connected to the ¼-inch (0.64-cm)-diameter nylon or polyethylene sampling tube and held in place as the loader empties a bucket of soil over the monitoring point. The desired depth of the monitoring point should be approximately 3 to 4 ft (0.9 to 1.2 m) below the pile top and a minimum of 1 ft (0.3m) above the uncontaminated soil (Figure 21). Although placement of the monitoring points is at the project manager's discretion, they should be installed to measure activity in various pile locations, such as at the edge, in the middle, and over the aeration pipe versus in between the pipes. The ¼-inch (0.64-cm)-diameter sampling tube should be long enough to extend 5 ft (1.5m) beyond the containment berm of the side nearest the point. Having the tube extend beyond the containment berm will enable easy access to the monitoring points without having to cut through or walk on the plastic pile cover.

Table 4. Monitoring Point Parts List

Part	**Supplier**	**Part #**
1/4-inch nylon tubing	Cole-Parmer	H-96141-44
NPT 3/8×1/4 tube fitting	NewAge Industries	5201098
female quick-connect	Forberg Scientific	4Z-Q4CN-BBP
gravel for strainer	any aquarium supply	none
3/8 inch thread tap	any hardware store	none
suction strainer 3/4 inch	Grainger	2P052
male quick-connect×1/4 inch tube	Forberg Scientific	4Z(A)-Q4P-BBP
mini-male thermocouple plug	L H Marshall	3060-K
thermocouple wire	L H Marshall	K24-1-508
quick-connect protectors	Forberg Scientific	CP-Q4C-BB

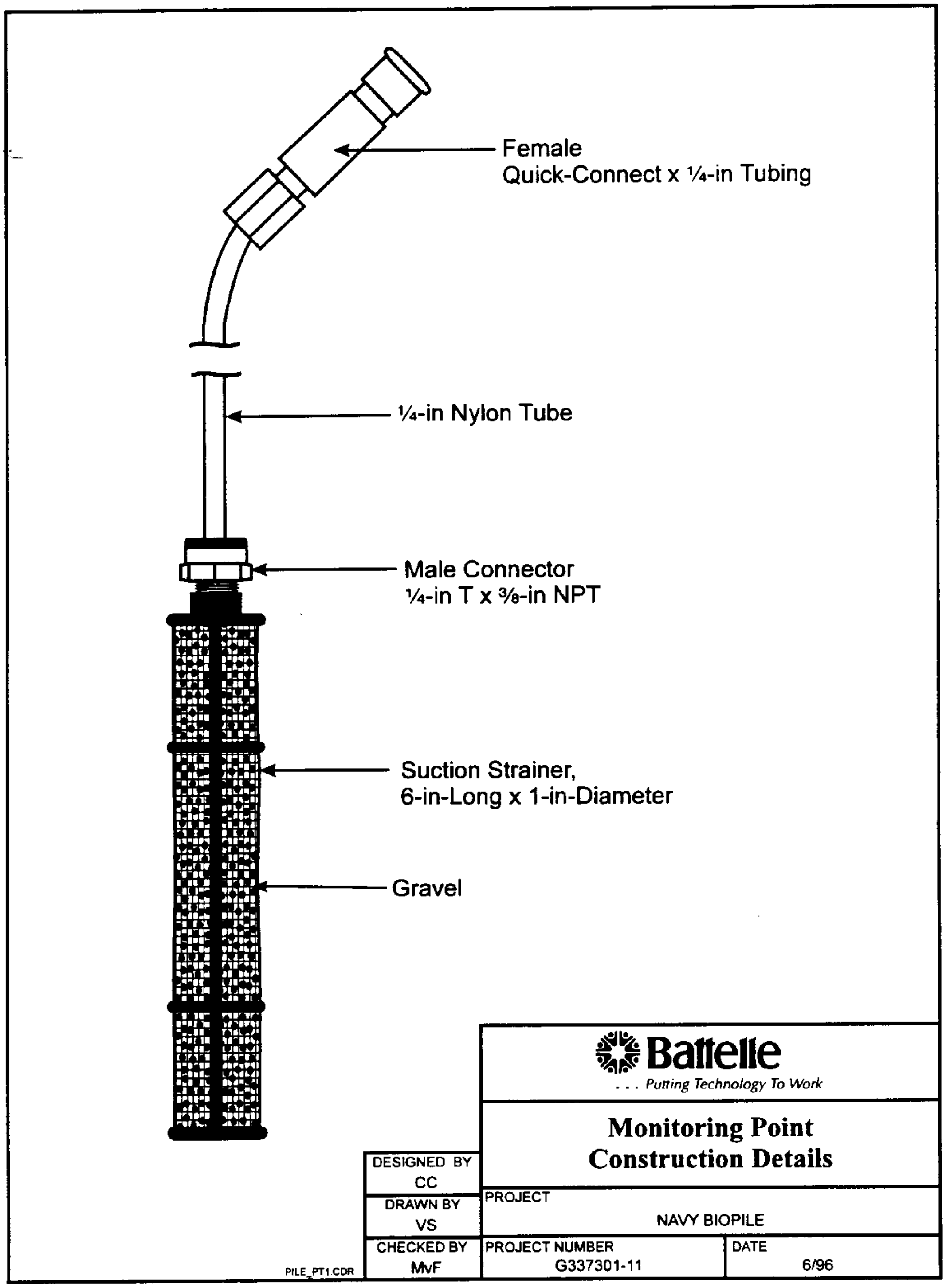


Figure 20. Typical Monitoring Point Construction

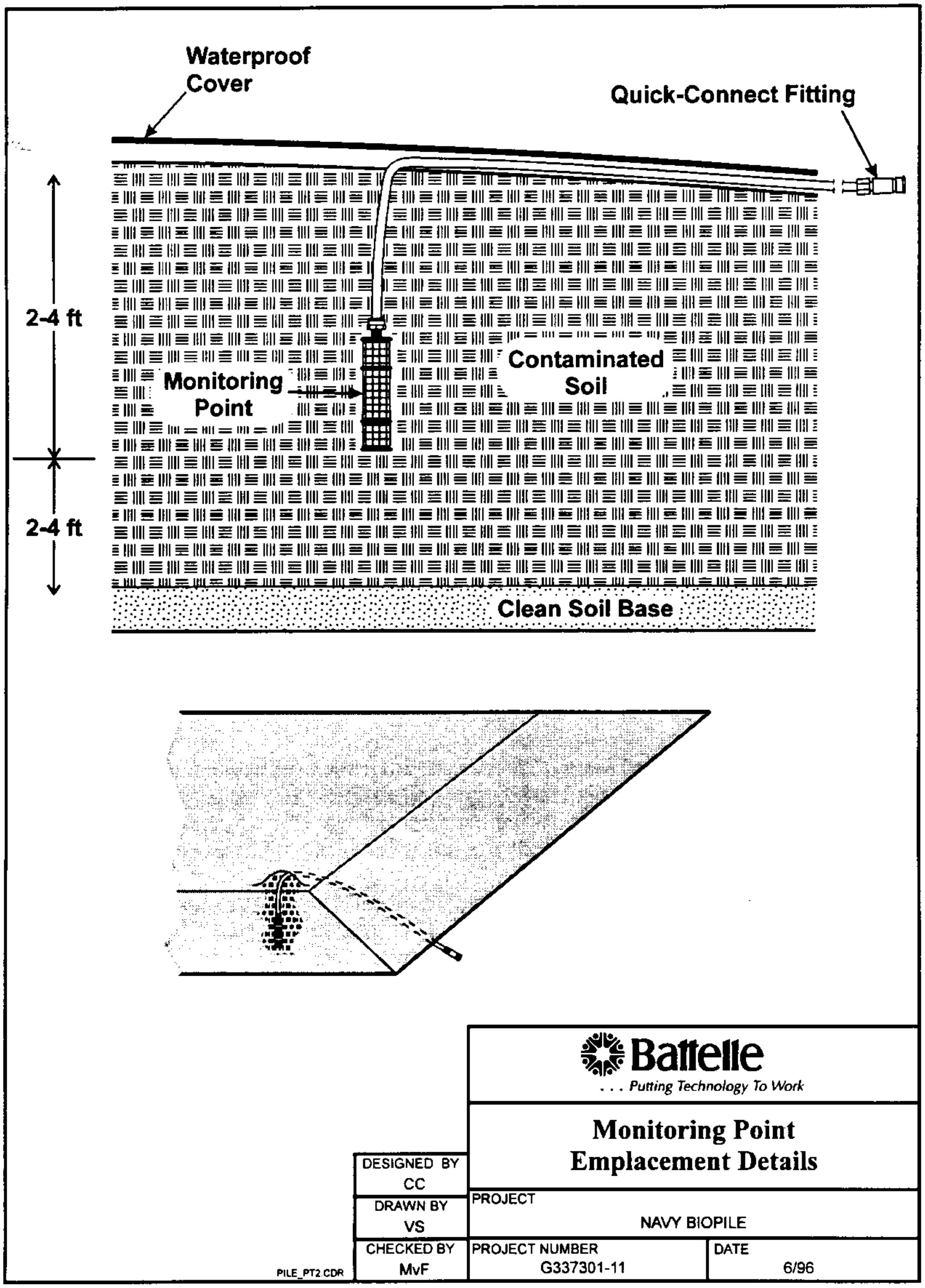


Figure 21. Suggested Monitoring Point Emplacement Technique.

The location of the soil gas monitoring points should be recorded, and all monitoring points should be labeled for data-recording purposes. The number of monitoring points to be installed will vary with the data collection requirements. Generally, 6 to 8 monitoring points will be sufficient for each 500-yd^3 (382-m^3) biopile.

To track soil temperature in the biopile, thermocouples or thermistors can be installed with the monitoring points. As with the soil gas sampling tubes, the thermocouple wire should be long enough to extend beyond the berm of the pad. If desired, moisture sensors can be installed to track the moisture content of the soil.

6.1.7.4 Time-Zero Sampling. Sampling the biopile upon completion of construction establishes initial biopile conditions that will serve as the reference point for the TPH degradation progress, microbial activity, and moisture variations over the treatment period. Two types of samples are required: soil samples and soil gas samples.

Soil samples are collected using a hand auger as described in Section 6.3. As a minimum guideline, one soil sample should be collected for every 100 yd^3 (76.5 m^3). A sampling frequency of 1 sample per 50 yd^3 (38.2 m^3) would be ideal if the contamination and soil property distributions are not known to be homogeneous. Soil samples are then transported to a laboratory and analyzed to establish the initial TPH concentration, BTEX concentration, moisture content, pH, microbial density in soil, and toxic metals concentration (if not already known).

Soil gas samples are taken by pulling a gas sample from the monitoring points installed during the biopile construction. Soil gas readings of O_2, CO_2, and TPH concentrations can be taken by pulling the sample directly through soil gas detectors: one detector for O_2 and CO_2 and a second one for TPH measurement. For off-line sampling, soil gas can be pulled through a vacuum pump to a Tedlar™ sample bag. The gas sample can then be transported to a laboratory for analysis.

Soil gas sampling can establish the effectiveness of the aeration system and can be used to establish the microbial activity via a respiration test. After placing the system into operation, the O_2 concentration profile of the soil gas at the different monitoring points is an indicator of the aeration effectiveness. Relatively consistent O_2 concentrations point to even aeration of the pile, which is desirable. In addition to aeration, a second point to consider is sufficient airflow rate. Measurements of O_2 concentration in the soil gas of 15 to 21% indicate the airflow rate is sufficient.

The respiration test is performed to establish the microbial activity in the soil that can be related to the TPH degradation rate. The respiration test is conducted by turning off the aeration pump and measuring the decrease in O_2 concentration and increase in CO_2 concentration with time. The more rapidly the O_2 concentration decreases, the more active the microbial population. Because aerobic microorganisms require O_2 to degrade TPH, the amount of O_2 consumed per time (consumption rate) can be related to the TPH degradation rate by using hexane as the representative TPH compound. Equation 1 shows the relationship between O_2 consumption and TPH degradation.

$$C_6H_{14} + 9\tfrac{1}{2}O_2 \longrightarrow 6CO_2 + 7H_2O \qquad (1)$$

Appendix I gives a step-by-step method for calculating the TPH degradation rate from respiration test data.

The quantity, depths, and locations of the soil samples and monitoring points should be recorded into the site record book. The locations can be fixed by using a grid coordinate system with one corner of the containment berm serving as the (0,0) coordinate reference point. A 75- or 100-ft (22.9 or 30.0-m) surveyor's measuring tape can be used to establish the soil sample and the monitoring point coordinate locations. Soil gas data should be recorded as it is collected.

6.1.7.5 Cover Installation. After the soil samples have been taken, the cover can be installed. The cover should be a waterproof plastic, such as HDPE, and should be 75 × 75 ft (22.9 × 22.9 m) in area. The thickness, approximately 12 to 20 mil, should be sufficient to make the cover resistant to stretching or tearing. The cover should be black or some other opaque color. White is least preferred because it reflects sunlight radiation the most.

Prior to covering the biopile, ensure that the monitoring point tubes extend beyond the containment berm, because they will need to be sandwiched between the containment berm and the cover to allow easy access for future soil gas sampling. Additionally, remove any sharp objects, such as wire, rebar, or jagged rocks, from the biopile top to prevent ripping the cover during installation. Ensure there are no low points in the center of the biopile that could serve as water collection areas. The cover should first be unfolded and inspected for any significant holes or tears, because any holes can allow rainwater to seep through the pile and cause a leachate problem. Pulling the cover over the biopile will require a minimum of 2 people. However, 3 or 4 persons would be preferable, because a tarp of that size will be heavy.

Once the cover has been pulled over the biopile and extends over the containment berm on all four sides, it can be secured by sandwiching it between the wood berm and 6-ft (1.8-m) sections of 2-inch×4-inch (5-cm×10-cm) beams. The 2×4s can be attached using 3-inch (7.6-cm)-long 5/16-inch (0.8-cm) lag screws. The screws should have a hex head to allow them to be driven with a drill. Leaving a 2- to 8-inch (5- to 20-cm) spacing between beams will create runoff channels for rainwater. The cover should be pulled snugly over the pile as the beams are installed. A snug cover will be less likely to rip during high winds than a loose cover.

Once the 2×4s have been attached to the cover and berm, nylon ropes can be used to tie the cover across the surface of the pile. To attach the ropes, drill three eye-screws to each side of the containment berm, placing one in the middle of each side and spacing the remaining two eye-screws an even distance to each side of the center. The nylon rope can be run through the eye-screws and over the pile in a “V” fashion as shown in Figure 22.

6.2 Permanent Biopile Design. The size and cover for a permanent biopile are the same as for the temporary system. The overall facility space requirements may be larger than for the temporary biopile system, because additional support facilities and space for future expansion may be desired. When planning a permanent biopile site, the following questions should be asked:

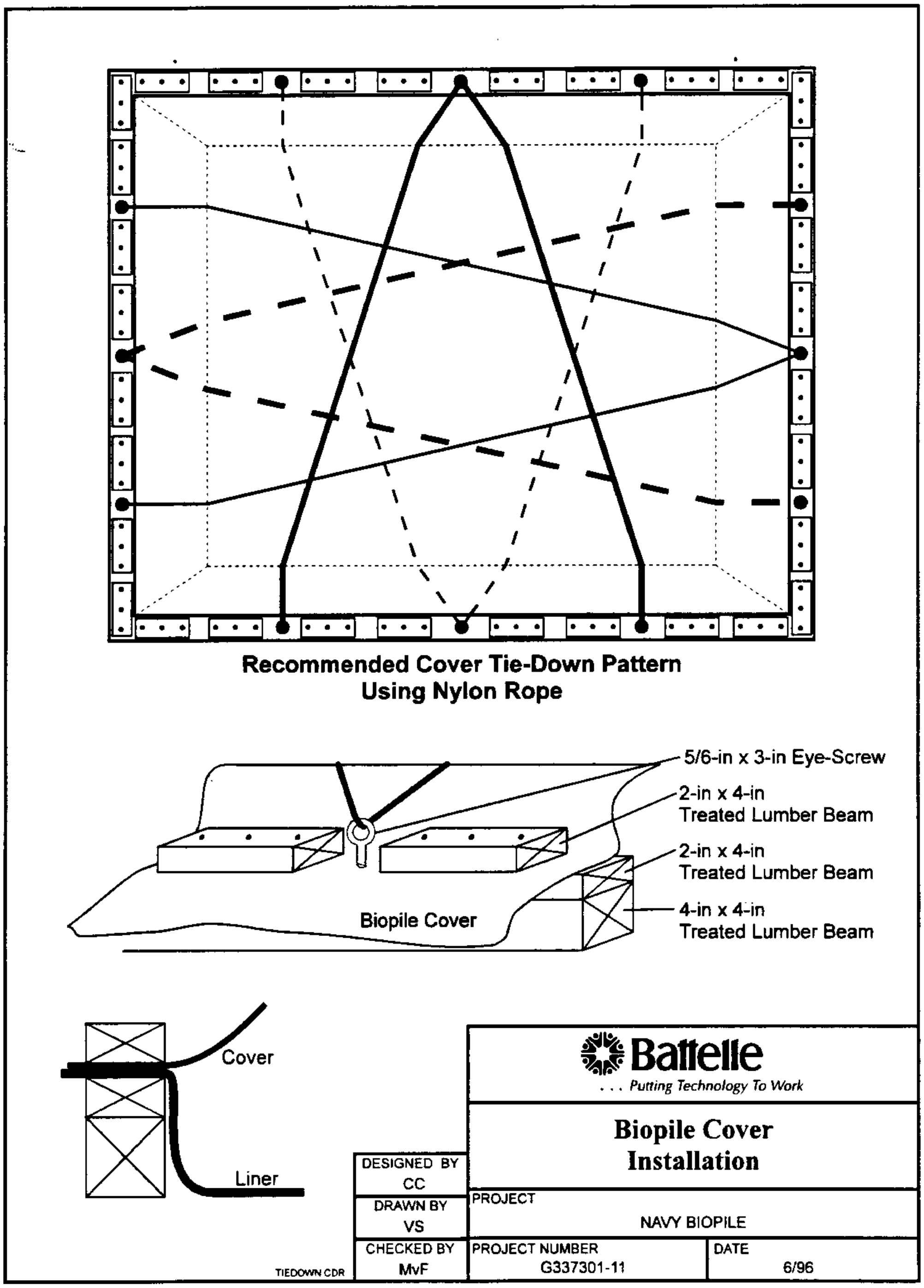


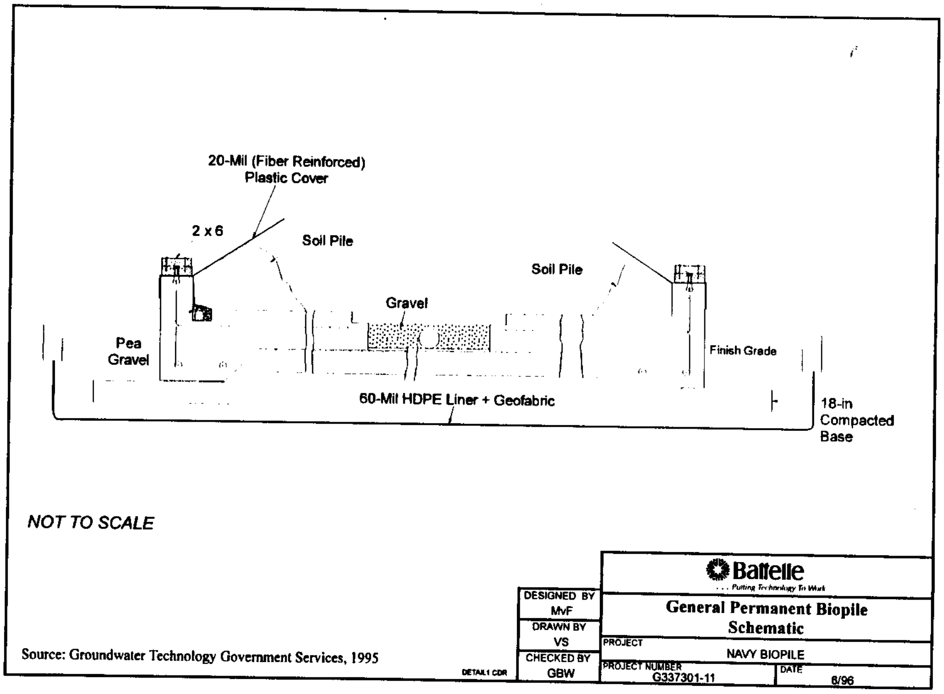
Figure 22. Suggested Pattern for Tying Down Biopile Cover with Nylon Rope.

- How much soil volume will be processed per month? The quantity will be used to calculate the number of biopile modules needed.

- What additional support features would be desirable?
- What, if any, possible need will there be for future expansions?

Any features a permanent site should have beyond the emplacement of the permanent biopile design will be site-specific. This section focuses on generally uniform features of permanent biopile sites, i.e., the design of the permanent biopile pad, the aeration system, the leachate collection system, the moisture addition system, and nutrient addition. Permanent biopile sites also may have upgraded support facilities, such as an equipment storage building, a designated equipment decontamination pad, and a building to serve as an office and control center. Other potential features would be a truck scale to track the amount of soil arriving and leaving the site and improved access roads and materials-handling areas. The extent to which facilities are upgraded is a function of site-specific needs and available funding.

6.2.1 Concrete Biopile Pad. The main difference between the temporary and permanent biopile designs is in the pad construction. The permanent biopile design will have a concrete pad that has an area of 50 ft × 60 ft (15.2 m × 18.3 m). The thickness of the concrete will be specified by the applicable construction guidelines. Figure 23 illustrates the general construction format of the permanent biopile cell. The example given in Figure 23 shows a 7-inch (17.8-cm)-thick concrete pad installed on an 18-inch (45.7-cm)-thick compacted fill foundation.



Source: Groundwater Technology Government Services, 1995

Figure 23. General Concrete Biopile Schematic.

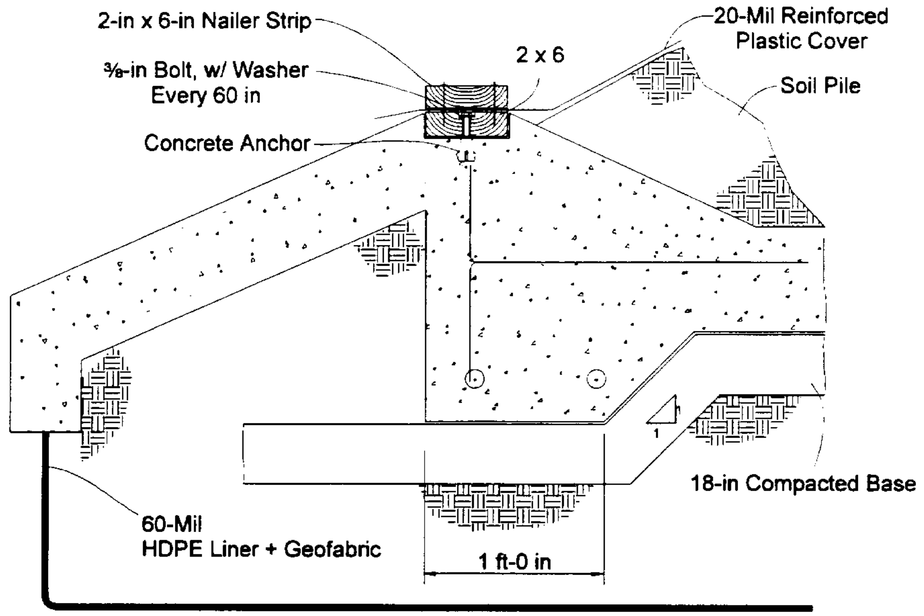
Whereas the temporary biopile pad liner is a 60-mil HDPE liner lying on the compacted base, the permanent pad liner should be composed of a 60-mil HDPE sheet laid on a geosynthetic liner emplaced directly beneath the compacted fill.

Unlike the temporary biopile, the aeration legs will be emplaced below grade in concrete channels and covered with pea gravel or similar material. The leachate containment berm should be approximately 6 inches (15.2 cm) high, constructed from concrete, and topped with a 3-inch × 3-inch (7.6-cm × 7.6-cm) pressure-treated wood nail rail attached to three sides of the berm. The fourth side, the one opposite the aeration line influent points, will have a 6-inch × 2-inch nail rail anchored to the top of the berm, because that is the side from which the loader will access the biopile. This nail rail will be used to anchor the cover to the biopile pad in a similar way as done on the temporary pile. Additionally, to enable easy access by the loader, a concrete ramp should be constructed on both sides of the berm on the side of the pad where the loader will enter to add contaminated soil. Figure 24 illustrates the construction of the biopile side that will serve as the loader access side. The actual pad design may vary, depending on the site conditions and client requirements.

6.2.2 Aeration System. Generally, there will be three aeration legs and therefore three channels in the concrete pad. Unlike the temporary biopile, the aeration legs will be emplaced below grade in 6-1/2-inch (16.5-cm) deep, 7-inch (17.8-cm) wide concrete channels and covered with pea gravel or similar material (Figure 25a). The aeration legs should be constructed of 2-inch (5.1-cm) diameter schedule 80 PVC pipe. The first 10 ft (3 m) of each aeration leg should be smooth pipe. The remaining 40 ft (12.2 m) should be slotted pipe. Where the aeration legs intersect, the concrete containment berm, the piping should be 2-inch (5.1-cm) diameter galvanized steel to reduce the risk of having to cut through the concrete berm to replace a cracked pipe (Figure 25b). The actual depth will be specified by the contractor or base engineer installing the pad. The channels will be approximately 40 ft (12.2 m) long, because the aeration pipe will only extend 40 ft (12.2 m) into the pile, to prevent short-circuiting of the air flowing into the pile from the ambient atmosphere.

The aeration leg channels can be connected to a leachate collection channel leading to the leachate collection tank. Figure 25 illustrates the aeration channels. As leachate generally will collect in the aeration channels, the channels should have a 1- to 2-degree slope toward the leachate collection channel that parallels the aeration header pipe and leads to the leachate collection sump. If the aeration system is operated in the extraction mode, the leachate collection system can be incorporated into the aeration system, as shown in Figure 3.

The aeration system could be automated by using either an on-off timer switch or a variable-speed vacuum pump controlled by a feedback loop with an O_2 sensor. The O_2 sensor would pull soil gas samples from several locations in the biopile, average the readings, and use a rule-based control routine to adjust the vacuum pump speed. Over aeration leads to premature drying of the soil. Using a simple process control loop to regulate the airflow rate by measuring the O_2 concentration in the pile will eliminate over aeration of the biopile and may reduce or eliminate the need to replace moisture during a biopile batch run.



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Joint Construction of the Concrete Pad Side Serving as the Loader Entrance Point

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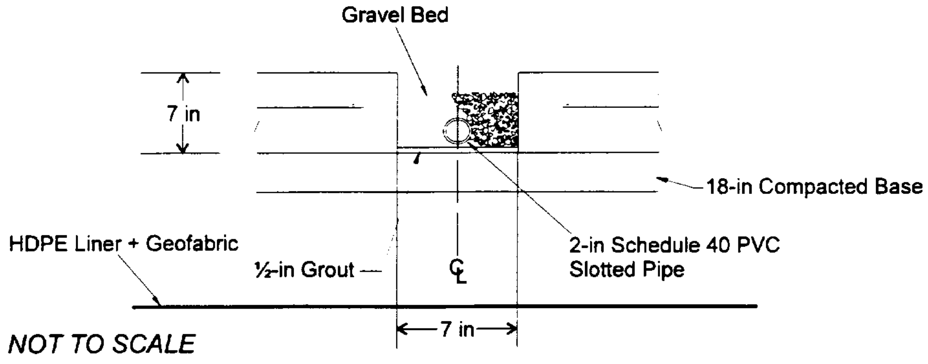
PROJECT NAVY BIOPILE
PROJECT NUMBER G337301-11
DATE 6/96
DETAIL3 CDR

Figure 24. Joint Construction of the Concrete Pad Side Serving as the Loader Entrance Point.

(a) Aeration Channel



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(b) Aeration Pipe Construction at Berm Intersection

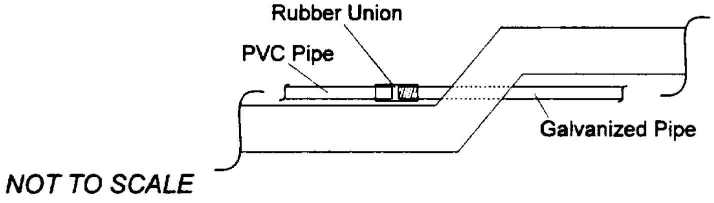

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Figure 25. PermanentBiopile Aeration System Design: (a) aeration channel; (b) aeration pipe construction atberm intersection.

As specified in Section 6.1.3, the air should be pulled through the biopile using either a 1½-hp (1,120-W) regenerative centrifugal blower (preferred) or a rotary-positive displacement blower capable of drawing approximately 120 scfm. The overall aeration system is described in Section 6.1.3.

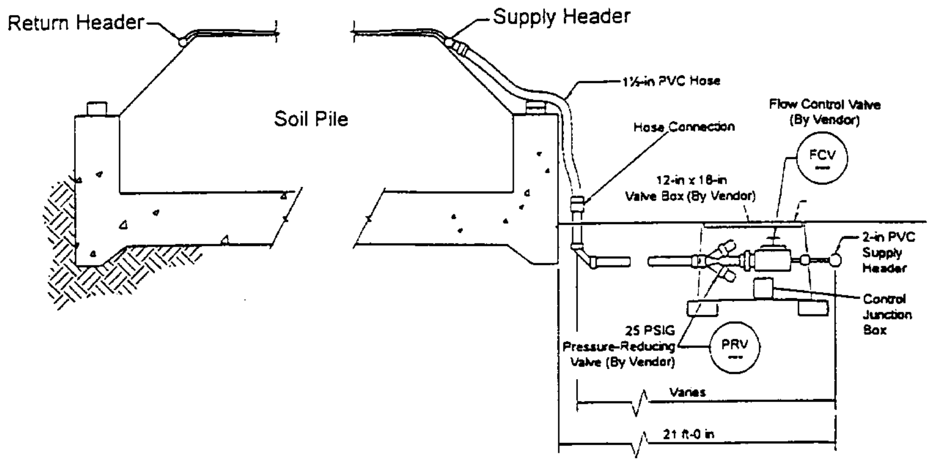
6.2.3 Leachate Collection System The leachate collection system will consist of the aeration pipe channels and a 4-inch to 6-inch (10.2-cm to 15.3-cm) leachate collection channel running parallel to the aeration header pipe inside of the containment berm. The collection channel should have a 1- to 2-degree slope toward one end of the channel where a 2-inch (5.1-cm)-diameter slotted PVC leachate collection pipe is located. The collection pipe is joined to a 2-inch (5.1-cm) galvanized steel union that traverses the concrete berm and reconnects to a 2-inch (5.1-cm) PVC transfer line leading to a _-hp transfer pump that pulls the leachate to the leachate collection tank. The pump can be activated by a liquid level controller (LLC) installed in the slotted PVC leachate collection pipe. The system can be set up so that stored leachate is recycled back to the biopile via the automated irrigation system described in Section 6.2.4. Alternatively, the leachate collection system may be incorporated with the aeration system, as shown in Figure 3.

6.2.4 Automated Irrigation System . An irrigation system is generally not needed but may be required in dry climates. Figure 26 shows a typical installed automated irrigation system. The system would consist of a flexible dripline or soaker hose that would be placed over the biopile in three or four discrete strips joined by a common feed line that would feed between the containment berm and the cover. Although not yet evaluated by NFESC, the irrigation system could be automated by placing moisture sensors in the biopile that would activate a water valve when the soil moisture content drops below a certain humidity. As an alternative, the irrigation line could be operated manually or via a timer switch.

6.2.5 Nutrient Addition. Nutrients can be added in several ways. Where possible, nutrients should be added as the biopile is being formed, by mixing nutrients in with the soil as it is being processed, by spraying a nutrient solution of known concentration on the soil as it is being placed on the biopile cell, or by adding dry nutrients with each bucket of soil. Table 5 indicates the composition of several agricultural chemicals that can be used to adjust the nutrient content of soils being prepared for biopile treatment.

Table 5. Types of Nutrient Sources

Name	Formula	Molecular Weight	Percent N:P:K	Vendor Quoted
Urea	$CO(NH_2)_2$	60.03	46:0:0	Lesco
Super phosphate	$Ca(H_2PO_4)_2$	234	0:27:0	Lockbourne Farmers' Exchange Co.
Potassium sulfate	K_2SO_4	174	0:0:45	Lesco
Diammonium phosphate	$(NH_3)_2PO_4$	129	22:24:0	Lesco



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DESIGNED BY MvF	**Schematic of an Installed Permanent Irrigation System**
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Figure 26. Schematic of an Installed Irrigation System

The irrigation system could double as a nutrient addition system by dissolving the nutrients and adding them in liquid form. Using the irrigation system to add nutrients would be especially useful in cases where batches require longer processing times, more than 4 months for example, or where it is seen as advantageous to add nutrients over the course of the process. One example of the latter case would be where a cometabolite, such as a supplemental carbon source, would be required to process a recalcitrant contaminant.

6.2.6 Soil Processing. The need to screen, shred, and blend soils will vary from site to site. For a permanent biopile facility, soil processing equipment requirements will be a function of the expected soil type and contamination level. The need to improve the soil condition should be weighed against the additional cost of leasing or purchasing soil-processing equipment.

Generally, soils with TPH contamination in excess of 50,000 mg/kg will require blending with uncontaminated or less-contaminated soil or with an organic amendment. Soils high in clay or silt content, or that are otherwise airflow limiting, will require shredding and blending with a bulking agent, such as rice hulls, wood chips, or shredded cardboard. Airflow limiting is defined in this document has having a soil void volume of less than 25%. Some highly contaminated soils pack tightly together to form large, sticky clumps. Air cannot effectively penetrate such clods. As a result, the microbial degradation rate and final achievable reduction in contamination will decline.

Shredding the soil and, as necessary, blending it with a bulking agent will increase the surface-to-volume ratio of the soil particles, thereby increasing the amount of contamination exposed to O_2 and the subsequent microbial degradation. Prior to feeding soil to a shredder, a screening step will be required to remove large rocks and foreign objects, such as metal rods and tires. Screening foreign objects from the soil will protect the shredder hardware and reduce the risk of projectiles shooting from the shredder. Upon being shredded, the soil can be fed to a soil mixer, such as a paddle mixer. This mixer can be truck-mounted or stationary and can be equipped with a load cell to measure the amount of soil, amendments, and water being fed. The mixer can serve to blend in nutrients and to add the required amount of moisture. Having a soil mixer provides the site operators with an ideal situation with respect to soil preparation. From the mixer, a loader can transport the processed soil to the biopile for treatment. Figure 27 illustrates a typical soil processing train.

6.3 Sampling and Analysis. This section outlines the sampling and analysis methods required for biopile design and routine monitoring activities. The procedures for soil, soil gas, and leachate collection are described in detail in this section, as well. Table 6 outlines the testing parameters for each matrix and lists the associated analytical methods for each test.

6.3.1 Soil Sampling Methods. A variety of methods are available to collect soil samples; however, the hand-auger sampling method is the best suited for sampling a biopile. Use the hand auger to bore a hole to approximately 1 ft (0.3 m) above the desired sampling depth. Next, use a slide hammer-type hand sampler, lined with brass sleeves (two 6-inch sections) to collect a core sample. Remove, cap, and label the two brass sleeves containing the soil sample. Upon labeling the samples, complete chain-of-custody form and place the sample in a cooler chilled with artificial ice. Upon completion of sampling, transport samples to a test lab.

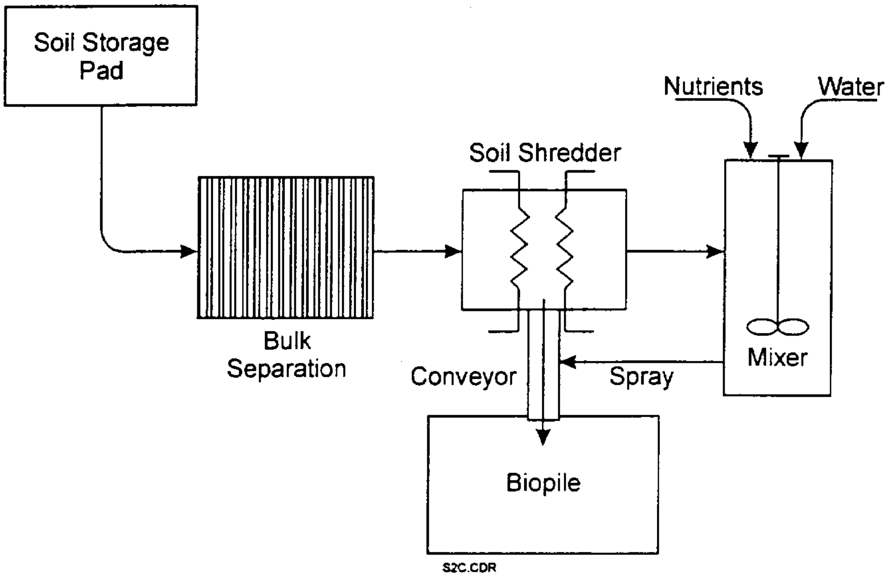

Figure 27. Typical Soil Processing Flowchart

6.3.2.1 Tedlar™ Sampling Bag Method. A Tedlar™ gas sampling bag is used to collect soil gas samples for field measurements. The soil gas samples are obtained from the soil gas monitoring points. Soil gas can be either pumped into the sampling bag using an inert pump or pulled into it by connecting the bag directly to the sample line and then placing the bag in a portable vacuum chamber. The soil gas sample will be analyzed on site using hand-held gas analyzers for O_2, CO_2, and TPH concentrations. Sampling by this technique is easy to perform, but care must be taken not to cross-contaminate samples through improper cleaning of the bags between samples. Before reusing the Tedlar™ bag, ensure that it is flushed twice with ambient air and once with soil gas.

Soil temperature data are collected by means of soil temperature thermocouples or thermistors placed in predetermined locations and depths during biopile construction. The data are collected through the temperature sensor lead located in the monitoring probe box. Temperature readouts are obtained by connecting a Fluke 52 or equivalent digital readout instrument to the temperature sensor lead and recording the digital readout. Soil gas in the biopile is sampled according to the following procedure:

Step 1. Connect the vacuum pump to the quick-connect coupling at the monitoring probe. A trap can be placed between the pump and the monitoring probe to collect any water that might be pulled from the monitoring probe.

Step 2. Connect the pump outflow to a 1-L Tedlar™ bag.

Step 3. Turn on the pump and fill the Tedlar™ bag with soil gas, making sure that the bag valve is in the open position.

Step 4. Flush the bag with soil gas twice using steps 1 through 3 and collect the final soil gas sample.

Step 5. Close the valve on the bag and disconnect the bag from the pump.

Step 6. Analyze the soil gas in the bag for oxygen, carbon dioxide, and TPH using a portable gas analyzer. Record the readings.

6.3.2.2 Direct Soil Gas Sampling Method. A convenient alternative to the Tedlar™ bag sampling method is to directly attach the gas detectors to the monitoring point lines via the quick-connect couplings.

Step 1. Calibrate the O_2/CO_2 detector and the TPH detector using the appropriate span gases.

Step 2. Attach the O_2/CO_2 detector to the monitoring point and draw soil gas through the detector until the reading stabilizes. Do not record the initial reading, because enough soil gas must clear through the detector to equal the amount originally in the monitoring point sampling line.

Step 3. Record the O_2 and CO_2 readings in the data record book.

Step 4. Repeat steps 1 through 3 using the TPH meter.

6.3.3 Leachate Sampling Method. Leachate samples should be collected by a grab sampling method. Grab samples of surface water are collected manually in a clean glass vessel and transferred immediately to a volatile organic analysis (VOA) vial. A Teflon™-lined cap is installed and the vial is inverted to ensure that there is zero headspace. Multiple vials may be filled from the single grab sample so that enough water is available for the analyses. After the sample is contained and properly labeled, it is shipped to a laboratory for the appropriate analyses.

Table 6. Summary of Analytical Methods forBiopile Design

Matrix	Characteristic	Analysis	Method	Method Objective Determines:
Soil	Physical	Soil classification	ASTM D 2488	The soil type as defined by the Unified Soil Classification System based on visual observations
		Particle-size distribution	ASTM D 422	Particle-size distribution by sieve size on a dry soil sample
		Bulk density	ASTM D 4532	The weight per unit volume of an oven-dried soil sample.
		Porosity	ASTM D 2434	The pore space in a soil sample by dividing its bulk density by the particle density.
		Moisture content	ASTM D 2216	The weight percent free water by oven-drying at 110°C.
		pH	EPA SW-846 Method 9045	pH of soil or waste by mixing the sample with reagent water and measuring the aqueous solution with a pH meter.
	Contamination	Total petroleum hydrocarbon oils	EPA SW-846 EPA Method 503	Oil and grease by a liquid / liquid extraction to collect organics for analysis by evaporation and gravimetric methods. Measures any of the heavier hydrocarbons includ-ing asphaltic materials and materials of biogenic origin.
	Nutrients	Total Kjeldahl nitrogen	EPA Method 351.4	Nitrogen through digestion of the sample followed by titration with the measurement of ammonia generation using a potentiometric or ion-selective electrode.
		Phosphorous, all forms	EPA Method 365.2	Specific forms of phosphorous through the reaction of the sample with reagents that generate complexes that are reduced by ascorbic acid. Colorimetric measurement is made using a spectrophotometer.
		Potassium	EPA Method 200.7 / 6010	Potassium through an acid digestion followed by elemental analysis by inductively coupled atomic plasma (ICAP) emission spectrometric method.
	Biological	Hydrocarbon degrader density	Standard Method 9215B	The indigenous microbial enumeration of hydrocarbon degraders through the inoculation of noble agar with local hydrocarbon contamination as the only available substrate for organisms isolated from the sample.
Soil Gas	Contaminant	Total petroleum hydrocarbon (TPH)	EPA Compendium Methods TO-3 (modified)	TPH concentrations in whole-air soil gas sample through cryofocused sample preconcentration followed by a gas chromatography / flame ionization / photoionization detection technique.
	Biological (Respiration)	Oxygen	Monitored with a GasTech instrument	The percent oxygen concentration in a whole-air soil gas sample.
		Carbon dioxide	Monitored with a GasTech instrument	The percent carbon dioxide concentration in a whole-air gas sample.
Leachate	Contaminant	TPH (oils)	EPA SW-846 Method 3510 EPA Method 503	Oil and grease content by a liquid / liquid extraction method to collect organics for analysis by evaporation and gravimetric methods. Measures any of the heavier hydrocarbon including asphaltic materials and materials of biogenic origin.

Section 7.0: REFERENCES

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APPENDIX A

GLOSSARY OF TERMS USED TO DESCRIBE BIOPILE DESIGN AND IMPLEMENTATION

acidity - measure of the hydrogen ion concentration of a solution

adsorption - the process by which molecules collect on and adhere to the surface of an adsorbent solid due to chemical or physical forces

aeration - process of supplying or introducing air into a medium such as soil or water

aerobic biodegradation - biodegradation occurring in the presence of oxygen

alkalinity - measure of the hydroxide ion concentration of a solution

ARAR - Applicable or Relevant and Appropriate Requirement

aromatic hydrocarbon - a class of hydrocarbons consisting of cyclic conjugate carbon atoms, e.g. benzene

asphaltene - a dark, solid constituent of petroleum that is soluble in carbon disulfide but not soluble in paraffin naphthas

BDAT - best demonstrated available technology

biodegradable - a material or compound that is able to be broken down by natural processes of living things such as metabolization by microorganisms

biodegrade - breaking down material (usually into more innocuous forms) by natural processes of living things such as metabolization by microorganisms

biodegradation rate - the mass of contaminant metabolized by microorganisms per unit time. In soil contamination this is normalized to the mass of soil and usually is expressed as mg contaminant degraded / kg soil-day (mg / kg-day).

biopile - soil pile constructed to allow aerobic bioremediation by aeration, possibly supplemented with water and nutrient additions

bioreactor - a container or area in which a biological reaction or biological activity takes place

bioremediation - general term for the technology of using biological processes such as microbial metabolism to degrade soil and water contaminants and decontaminate sites

bioventing - an in situ soil aeration process designed and operated to maximize the biodegradation of organic compounds, with some volatilization occurring

blower - a unit of rotating mechanical equipment used to increase the pressure in a gas stream and providing a total pressure rise of more than 4 inches of water and less than 14.7 psi

BTEX - benzene, toluene, ethylbenzene, and xylenes

bulking agent - biodegradable organic material, such as rice hulls or wood chips, added to improve the permeability, water-holding capacity, or other properties of soil to be treated in a biopile

C - carbon

CAA - Clean Air Act

CFR - Code of Federal Regulations

CFU - colony-forming unit. Measuring the number of CFUs is a low-cost screening method to determine the ability of a contaminated matrix to sustain microbial action.

clay - fine-grained soil that can exhibit putty-like properties within a range of water content and which shows considerable strength when air-dry

contaminant - something that makes material in contact with it impure, unfit, or unsafe; a pollutant

CWA - Clean Water Act

cycloalkene - unsaturated, monocyclic hydrocarbon with the formula C_nH_{2n-2}

DC - direct current

DOD - U.S. Department of Defense

ex situ - refers to a technology or process for which contaminated material must be removed from the site of contamination for treatment

extraction - aerating the biopile by removing air under vacuum to induce airflow

FC - field capacity

FID - flame ionization detector

field capacity - the amount of water held in soil after excess water has drained away and after the rate of downward drainage has become negligible

free product - organic contaminant existing as a separate liquid phase

GAC - granular activated carbon

GC - gas chromatograph

hand-auger drilling - hand-drilling by rotating a spiral channel supported on a shaft

HC - hydrocarbon

HDPE - high-density polyethylene

head - the pressure difference between two places, an energy term expressed in length units

Henry's law constant - the partial pressure exerted by a compound divided by the concentration of the compound in aqueous solution. The Henry's law constant of low-solubility compounds can be approximated as the ratio of the pure component vapor pressure and the water solubility.

heterotrophic bacteria - bacteria that obtain energy and carbon from organic molecules

ICAP - inductively coupled atomic plasma

ICE - internal combustion engine

impermeable membrane - sheeting material designed to retain water

injection - aerating the biopile by forcing in air under vacuum to induce airflow

in situ remediation - a treatment process that can be carried out within the site of contamination without bulk excavation

JP - jet propulsion (fuel)

K - elemental potassium

LDR - Land Disposal Restriction

leachate collection point - sand-filled area to which biopile leachate drains and from which leachate is transferred to the collection tank via a leachate suction line

LLC - liquid level controller

LNAPL - light, nonaqueous-phase liquid

MCL - maximum contaminant level

MCLG - maximum contaminant level goal

mineralization - the complete conversion of an organic compound to inorganic products (principally water and carbon dioxide)

monitoring point - soil gas sampling port consisting of a porous gas collection port connected to tubing that is placed in the biopile to allow withdrawal of a gas sample for analysis

N - elemental nitrogen

NAAQS - National Ambient Air Quality Standards

NFESC - Naval Facilities Engineering Service Center

NPDES - National Pollutant Discharge Elimination System

nutrient amendment - chemical or organic fertilizer, usually rich in nitrogen, phosphorus, or potassium, that is added to support life and growth of microorganisms in the biopile

O_2 - molecular oxygen

off-gas - gaseous effluent, possibly containing contaminant vapors, that leaves a process, typically from a point source during process operations

OSHA - Occupational Safety and Health Administration; Occupational Safety and Health Act

oxygen use rate - rate of oxygen consumption due to biological and chemical action (used to determine respiration rate when the chemical oxygen demand is negligible)

permeability - measure of the capacity of a rock, soil, or sediment to allow passage of liquid or gas through pores without damage to the structure of the media

PAH - polycyclic aromatic hydrocarbon

PCB - polychlorinated biphenyl

pH - measure of the acidity or alkalinity of a solution; the negative log of the hydrogen ion activity

PID - photoionization detector

pipe schedule - standard method for designating the wall thickness of pipe

pore space - the open space and minute passages in a solid material

porosity - measure of the amount of available pore space in a material through which liquid and gas can move

POTW - publicly owned treatment works

ppmv - part(s) per million by volume (indicates vapor concentration)

PVC - polyvinyl chloride

RA - remedial action

RCRA - Resource Conservation and Recovery Act

remediation - activity involved with reducing the risk from a contaminated site

respiration - oxidation of compounds to provide energy for cells

respiration rate - rate of reduction of oxygen concentration due to biological action

respiration test - test used to provide rapid field measurement of biodegradation rates to determine the potential applicability of aerobic bioremediation at a contaminated site and to provide information for a full-scale treatment system design

rH - relative humidity

sand - unconsolidated rock and mineral particles with diameters ranging from 1/16 to 2 mm

scfm - standard cubic feet per minute

shredding - mixing and grinding soil to improve homogeneity and increase permeability

short-circuiting - undesirable condition in which air flows unevenly through the biopile due to the existence of low-resistance pathways

silt - unconsolidated rock and mineral particles with diameters ranging from 0.0002 to 0.05 mm

sLm - standard liter per minute

soil gas - mixture of air and vapors in soil porosity

soil gas permeability - a soil's capacity to allow gas flow. The soil gas permeability varies according to grain size, soil uniformity, porosity, and moisture content.

soil matrix - soil as the environmental media containing contaminants

soil type - system of classification of soils based on physical properties

soil vapor extraction - an in situ soil aeration process designed and operated to maximize the volatilization of low-molecular-weight compounds, with some biodegradation occurring

sorbed phase - the thin layer of material held near the surface of soil particles by physical and chemical interactions

sorption - general term for physical and chemical absorption and adsorption phenomena

substrate - the base on which an organism lives; reactant in microbial respiration reaction (electron donor)

surfactant - surface active agent that reduces the surface tension of liquids or the interfacial tension between two liquids or a liquid and a solid

TBC - to be considered

TPH - total petroleum hydrocarbons

treatability study - a planned group of measurements, bench-scale studies, or pilot-scale studies performed to measure the effectiveness of a process option for remediating a contaminated site or to collect design data for implementing a process option

TSCA - Toxic Substances Control Act

USACE - U.S. Army Corps of Engineers

USC - United States Code

USCS - Unified Soil Classification System

U.S. DoD - United States Department of Defense

U.S. EPA - United States Environmental Protection Agency

UST - underground storage tank

vacuum pump - a unit of mechanical equipment used to increase the pressure in a gas stream and providing a nearly complete vacuum at the suction flange

vapor pressure - the pressure exerted by a single component phase at a given temperature

vaporization - transfer of a chemical substance from the liquid or solid state to the gaseous state

VOA - volatile organic analysis

VOC - volatile organic compound

volatile - easily vaporized at relatively low temperatures

water table - planar surface between the vadose zone and the saturated zone

wetting - adding water to increase the moisture content of the soil prior to constructing the biopile or during biopile operation

APPENDIX B

OVERVIEW OF APPLICABLE FEDERAL ENVIRONMENTAL REGULATIONS

This appendix is divided into two sections. The first section covers major federal statutes and regulations related to site remediation and hazardous waste management. The second section gives an overview of various chemical-, location-, and action-specific regulations. This appendix is designed to give the reader an introduction to the various environmental regulations and statutes that may apply to the construction, operation, and closeout of a biopile facility. For more specific details, the reader should reference the *Code of Federal Regulations* or the *Federal Register*. Additionally, Appendices C and D list various state and U.S. EPA hazardous waste management points of contact.

B.1 Summary of Major Federal Statutes and Regulations. This section provides general information about the major federal environmental regulations that may apply to biopile remediation sites.

B.1.1 Resource Conservation and Recovery Act. The Resource Conservation and Recovery Act (RCRA) establishes rules for hazardous waste and underground storage tank (UST) corrective action plans. RCRA regulates wastes that are hazardous by characteristic (corrosive, ignitable, reactive, toxic) (40 CFR 261.20 through 261.24, “Subpart C, Characteristics of Hazardous Waste”) and specifically listed hazardous wastes (40 CFR 261.30 through 261.33, “Subpart D, Lists of Hazardous Wastes”). Federal UST regulations (40 CFR Part 280) do not provide specific soil cleanup standards, but methods for developing cleanup standards are included in the regulations.

B.1.2 Clean Air Act of 1990 (42 USC 7401-7642). The Clean Air Act (CAA) established standards for vapor and particulate air emissions. In addition to these federal standards, local authorities usually have air release permitting requirements. These release standards vary widely and may range from little or no formal regulation to contaminant-specific mass discharge rates. Some authorities base their standards on the concentration at the nearest receptor, but others consider each site on a case-by-case basis.

B.1.3 Clean Water Act (33 USC 1251-1376). The Clean Water Act (CWA) sets standards and requirements for pollutant discharge to surface waters. The National Pollutant Discharge Elimination System (NPDES) (40 CFR Parts 122 and 125) requires permits for the discharge of pollutants from any point source into the waters of the United States. General pretreatment regulations for publicly owned treatment works (POTW) are enforceable standards if remediation results in discharge to a POTW.

B.1.4 Safe Drinking Water Act (40 USC 300). The Safe Drinking Water Act established both the National Primary Drinking Water Regulations (40 CFR Part 141) and National Secondary Drinking Water Regulations (40 CFR Part 143). Primary maximum contaminant levels (MCLs) are enforceable standards for contaminants in the public drinking water supply systems. These are set with regard to health factors, economic feasibility, and the technical feasibility of removing a contaminant from a water supply system. Secondary MCLs are intended as guidelines to protect the public welfare. These are contaminants which may adversely affect the aesthetic quality of drinking water such as taste, odor, color, and appearance and that may deter public acceptance of drinking water provided by public water systems.

Maximum contaminant level goals (MCLGs) exist for several organic and inorganic compounds found in drinking water. These are nonenforceable guidelines that consider only health factors.

B.1.5 U.S. Water Quality Criteria, 1986. The water quality criteria (U.S. EPA, 1986) are concentrations of pollutants calculated for ambient surface water quality to protect human health and aquatic life. Criteria are set for both acute and chronic effects. These usually are nonenforceable concentrations unless they have been adopted by a state as part of the state’s water quality standards. These criteria present useful guidance on the environmental effects of pollutants and may be included as conditions when setting remedial action objectives.

B.2 Types of Regulations. This section outlines chemical-, location-, and action-specific regulations.

B.2.1 Chemical-Specific Regulations. Chemical-specific regulations are numeric values, usually total limits or concentration ranges, for specific chemicals in water, soil, and air. These limits are either health-based or risk-based standards modified to consider the economic and technical possibility of implementation. Examples of this type of regulation include: soil, groundwater, and RCRA concentration-based treatment standards; MCLs for public drinking water; and National Ambient Air Quality Standards (NAAQS) for air quality. Table B-1 provides a review of some chemical-specific regulations.

Table B-1. Review of Potential Chemical-Specific Regulations

Law/Regulation	Description
Resource Conservation and Recovery Act (RCRA); 40 CFR Parts 260-280	This act establishes MCLs for groundwater and treatment standards [based on best demonstrated available technologies (BDAT)] for hazardous wastes covered by the Land Disposal Restrictions (LDRs).
Federal Clean Air Act; 40 CFR Parts 50-80	This act sets limits on levels of air pollutants.
Federal Clean Water Act; 40 CFR Parts100-140, 400-470	This act sets limits on levels of water pollutants.
Safe Drinking Water Act; 40 CFR Parts141, 143, 260-280 Underground Injection Control Regulations; 40 CFR Parts 144-147	This act and these regulations establishes MCLs and MCLGs for drinking water supplies.
U.S. Water Quality Criteria	These are criteria for ambient surface water quality established to protect human health and aquatic life. These are not standards and have no direct regulatory authority but may be included as to be considered (TBC) criteria.
Occupational Safety and Health Act (OSHA); 29 USC 651-678; 29 CFR Parts 1904, 1910, 1926	This act provides occupational safety and health requirements applicable to workers engaged in on-site field activities.

B.2.2 Location-Specific Regulations. Location-specific regulations limit activity in an area, because of the unique or delicate nature of the site or its surroundings. These regulations vary widely with location. Some examples of locations which usually face constraints in remediation actions include protected floodplains; wetlands; endangered species habitats; and archaeologically or historically important sites. Some federal location-specific regulations are reviewed by category in Table B-2.

Table B-2. Review of Potential Location-Specific Regulations

Location-Specific Factor	Citation	Requirement
Seismicity	Location Standards, Permitted Hazardous Waste Facilities; 40CFR 264.18	Facilities must not be located within 200feet of a fault that has been displaced in Holocene time.
Wilderness Areas, Wildlife	Fish and Wildlife Coordination Act; 16 USC 661 et seq.	This act requires that actions affecting fish and wildlife must include provisions to protect the affected fish and wildlife resources.
	Wild and Scenic Rivers Act; 16USC 1271 et seq.	This act protects designated rivers or river sections in the National Wild and Scenic Rivers System.
	Wilderness; Act 16 USC 1131 etseq.	This act protects and restricts activities in areas designated as part of the National Wilderness Preservation System.

Location-Specific Factor	Citation	Requirement
Wetlands, Floodplains	Executive Order 11990; Protection of Wetlands; 40 CFR Part 6, Appendix A; 40 CFR 6.302(a)	Federal agencies must take action to avoid adverse impacts, to minimize potential harm, and to preserve and enhance wetlands to the extent possible.
	Executive Order 11988; Protection of Floodplains	Adverse effects associated with the development of a floodplain must be evaluated.
	40 CFR Part 6, Appendix A	Federal agencies are required to incorporate floodplain management goals and wetlands protection considerations in their planning, regulatory, and decision-making process.
	40 CFR Part 6, Appendix A	Federal agencies should avoid new construction in wetlands areas.
	Clean Water Act §404; 40 CFR 230.10; 33 CFR Parts 320-330	This act prohibits discharge of dredge or fill material into wetlands without a permit.
Wetlands, Floodplains (continued)	Clean Water Act §404(b)(1)	This act provides for the enhancement, restoration, or creation of alternative wetlands.

	Location Standards, Permitted Hazardous Waste Facilities; 40CFR 264.18	This regulation requires facility design to prevent washout of hazardous waste.
Critical habitat upon which an endangered or threatened species depends	Endangered Species Act of 1973; 16 USC 1531 et seq.; 50 CFR Parts 200 and 402 Fish and Wildlife Coordination Act; 16 USC 661 et seq. Fish & Wildlife Conservation Act 16 USC 2901	Individuals must take action to conserve endangered or threatened species and must not destroy or adversely modify critical habitat. Individuals must consult with Department of Interior, Fish and Wildlife Service, and state personnel required to ascertain that proposed actions will not affect any listed species.
Within areas where action may cause irreparable harm, loss, or destruction of significant artifacts	Archaeological and Historic Preservation Act; 16 USC 469 to 469c-1	Individuals must take action to recover and preserve artifacts.
Property included in or eligible for the National Registry of Historic Places	National Historic Preservation Act; 16 USC 470 et seq.; 36 CFR 800.1 National Historic Landmarks Program; 36 CFR 65 National Register of Historic Places; 36 CFR Part 60	Individuals must take action to preserve historic properties and plan actions to minimize harm to National Historic Landmarks.
	Executive Order 11593; 36 CFR 800.4	Federal agencies must identify possible effects of proposed remedial activities on historic properties, and measures must be implemented to minimize or mitigate potential effects.
Archaeological sites or resources on public land	Archaeological Resources Protection Act of 1979; 16 USC 470aa-11; 43 CFR Part 7	Individuals must take steps to protect resources and to preserve data.

B.2.3 Action-Specific Regulations. Action-specific regulations, summarized in Table B-3, are rules that apply to specific technologies or activities. Examples of some action-specific regulations include monitoring requirements; effluent and leachate discharge limits from specific processes; hazardous waste manifesting requirements; and worker health and safety requirements. Air and water discharges from the biopile will be required to meet permitting standards set by local jurisdictions.

Table B-3. Review of Potential Action-Specific Regulations

Law/Regulation	Comments
Resource Conservation and Recovery Act (RCRA) EPA Regulations for Hazardous Waste; 40 CFR Parts 260 through 270	These rules establish a comprehensive cradle-to-grave program for safe management of hazardous waste. Contaminated soils that are sufficiently similar to hazardous waste under RCRA or state regulations may be affected by these regulations as applicable or relevant and appropriate requirements (ARARs) or as to be considered (TBC) guidance.
EPA Underground Storage Tank Requirements; 40 CFR Part 280	These regulations provide a regulatory program for underground storage tanks.
Toxic Substances Control Act; 15 USC 2601 et seq.	This act provides for regulation of specific toxic substances, including polychlorinated biphenyls (PCBs).
Federal Insecticide, Fungicide, and Rodenticide Act; 7 USC 136 et seq.	This act provides for regulation of the production, use, and disposal of pesticides.
National Environmental Policy Act; 42 USC 4321 et seq.	This act requires that all major federal actions be evaluated for potential impacts on the environment.
Pollution Prevention Act of 1990; 42 USC 13101 et seq.	This act encourages eliminating or reducing the production of hazardous or toxic wastes at the source and responsible recycling.

B.3 Regulatory Summary. Not all of the previous regulations apply specifically to biopiles, although they do apply to general environmental remediation. Some regulations do apply to certain parts of the biopile process. The CAA regulates vapor emissions from biopiles, and the CWA regulates fluid emissions from biopiles. Disposal of some soils containing wastes regulated by the Toxic Substances Control Act (TSCA) or by RCRA may be prohibited in certain landfills or in certain mixtures. Occupational Safety and Health Act (OSHA) standards must be followed to protect field personnel. Location-specific regulations also may apply specifically to biopiles.

B.4 Reference for Appendix B

U.S. Environmental Protection Agency. 1986. *Quality Criteria for Water 1986.* EPA 440/5-86-001. Office of Water, Washington, DC. May 1. (Also with Update No. 1, 1986, and Update No. 2, 1987.)

APPENDIX C

STATE ENVIRONMENTAL REGULATORY AGENCIES

ALABAMA
Alabama Dept of Environmental Management
Land Division
1751 Federal Drive
Montgomery, AL 36130
334-271-7730

ALASKA
Dept. of Environmental Conservation
410 Willoughby Avenue, Suite 105
Juneau, AK 99801-1795
Program Manager: 907-465-5150

Northern Regional Office
610 University Avenue
Fairbanks, AK 99709

ARIZONA
Arizona Dept. of Environmental Quality
Waste Programs Bureau
3033 North Central Avenue
Phoenix, AZ 85012
602-207-2300

ARKANSAS
Dept. of Pollution Control and Ecology
Hazardous Waste Division
P.O. Box 8913
8001 National Drive
Little Rock, AR 72209-8913
501-682-0833

CALIFORNIA
California EPA
Dept. of Toxic Substances Control
400 P Street, 4th Floor
P.0. Box 806
Sacramento, CA 95812-0806
916-322-0504

California EPA
State Water Resources Control Board
Water Resources Control Board
P.O. Box 100
Sacramento, CA 95812-0100
916-657-2390

COLORADO
Public and Environment Dept.
Hazardous Materials and Waste Management Division
4300 Cherry Creek Drive South
Denver, CO 80222
303-692-3300

CONNECTICUT
Dept. of Environmental Protection
Waste Management Bureau
Waste Engineering and Enforcement Division
79 Elm Street
Hartford, CT 06106
203-424-3023

Connecticut Resource
Recovery Authority
179 Allyn Street, Suite 603
Professional Building
Hartford, CT 06103
203-549-6390

DELAWARE
Dept. of Natural Resources and Environmental Control
Division of Air and Waste Management
Hazardous Waste Office
89 King's Highway
P.0. Box 1041
Dover, DE 19903
302-739-3689

DISTRICT OF COLUMBIA
Dept. of Consumer and Regulatory Affairs
Environmental Regulation Administration
Pesticides and Hazardous Waste Management Branch
2100 Martin Luther King Avenue, SE, Suite 203
Washington, DC 20020
202-645-6617

FLORIDA
Environmental Protection Dept.
Waste Management Division
Solid and Hazardous Waste Bureau
2600 Blair Stone Road
Tallahassee, FL 32399-2400
904-488-0300

GEORGIA
Georgia Dept. of Natural Resources
Environmental Protection Division
Hazardous Waste Management Branch
Floyd Towers East, Suite 1154
205 Butler Street, SE
Atlanta, GA 30334
404-656-7802

HAWAII
Dept. of Health
Solid and Hazardous Waste Branch
919 Alamoana Boulevard, Room 212
Honolulu, HI 96814
808-586-4225

IDAHO
Dept of Health and Welfare
Division of Environmental Quality
1410 N Hilton
Boise, ID 83706
208-334-5840

ILLINOIS
Department of Commerce and Community Affairs
Solid Waste Division
325 West Adams Street
Springfield, IL 62704
217-785-2800

INDIANA
Dept. of Environmental Management
Office of Solid and Hazardous Waste
100 North Senate Avenue
Indianapolis, IN 46204
317-232-3210

IOWA
Dept. of Natural Resources
Waste Management Assistance Division
502 E 9th Street
Wallace State Office Building
Des Moines, IA 50319-0034
515-281-8681

KANSAS
Dept. of Health and Environment
Bureau of Waste Management
Forbes Field, Building 740
Topeka, KS 66620
913-296-1612

KENTUCKY
Natural Resources and Environmental Protection Cabinet
Division of Waste Management
14 Reilly Road
Frankfort, KY 40601
502-564-6716

LOUISIANA
Dept. of Environmental Quality
Solid and Hazardous Waste Division
7290 Bluebonnet Boulevard
Baton Rouge, LA 70810
504-765-0249

MAINE
Dept. of Environmental Protection
Bureau of Hazardous Materials and Solid Waste Control
Hospital Street
Ray Building
State House Station #17
Augusta, ME 04333
207-287-2651

MARYLAND
Environment Dept.
Waste Management Administration
2500 Broening Highway
Baltimore, MD 21201
410-631-3304

MASSACHUSETTS
Dept. of Environmental Protection
Hazardous Waste Division
One Winter Street, 7th Floor
Boston, MA 02108
617-292-5853

MICHIGAN
Michigan Dept. of Natural Resources
Waste Management Division
608 West Allegen
Lansing, MI 48933
517-373-2730

MINNESOTA
Pollution Control Agency
Hazardous Waste Division
520 Lafayette Road North
St. Paul, MN 55155-4194
612-297-8502

MISSISSIPPI
Dept. of Environmental Quality
Division of Solid and Hazardous Waste Management
2380 Highway 80 West
Jackson, MS 39204
601-961-5047

MISSOURI
Dept. of Natural Resources
Waste Management Program
205 Jefferson, 13th Floor
Jefferson City, MO 65101
314-751-3176
Missouri Natural Resources Hotline: 800-334-6946

MONTANA
Dept. of Health and Environmental Sciences
Waste Management Division
P.O. Box 200901
Helena, MT 59620-0901
406-444-1430

NEBRASKA
Environmental Quality Dept.
P.O. Box 98922
1200 N Street, Suite 400
Lincoln, NE 68509
402-471-2186

NEVADA
Conservation and Natural Resources Dept.
Division of Environmental Protection
Waste Management Program
123 West Nye
Carson City, NV 89710
702-687-4670

NEW HAMPSHIRE
Dept. of Environmental Services
Waste Management Division
Health and Welfare Building
6 Hazen Drive
Concord, NH 03301
603-271-2900

NEW JERSEY
Dept. of Environmental Protection and Energy
Solid Waste Management
120 S Stockton Street, CN 414
Trenton, NJ 08625-0414
609-984-6880

NEW MEXICO
Environmental Improvement Division
Hazardous Waste Bureau
P.O. Box 26110
1190 St. Francis
Santa Fe, NM 87502
505-827-2775

NEW YORK
Dept. of Environmental Conservation
Division of Solid Waste and Hazardous Materials
50 Wolf Road, Room 488
Albany, NY 12233
518-457-6934
SQG Hotline: 800-462-6553

NORTH CAROLINA
Dept. of Environmental, Health, and Natural Resources
Hazardous Waste Section
512 North Salisbury Street
Raleigh, NC 27604
919-715-4140

NORTH DAKOTA
Dept. of Health
Consolidated Laboratories
Division of Waste Management
1200 Missouri Avenue
Bismarck, ND 58504
701-328-5166

OHIO
Ohio EPA
Division of Hazardous Waste
1800 Watermark Drive
Columbus, OH 43215-1099
614-644-2917

OKLAHOMA
Environmental Quality Dept.
Hazardous Waste Management Division
1000 NE Tenth Street
Oklahoma City, OK 73117
405-271-5338

OREGON
Dept. of Environmental Quality
Hazardous Waste Division
811 SW Sixth Avenue
Portland, OR 97204
503-229-5913

PENNSYLVANIA
Dept. of Environmental Resources
Bureau of Waste Management
Director's Office
400 Market Street
P.O. Box 2063
Harrisburg, PA 17105
717-787-9870

RHODE ISLAND
Dept. of Environmental Management
Division of Waste Management
291 Promenade Street
Providence, RI 02908
401-277-4700

SOUTH CAROLINA
Dept. of Health and Environmental Control
Bureau of Solid and Hazardous Waste Management
2600 Bull Street
Columbia, SC 29201
803-734-5202

SOUTH DAKOTA
Dept. of Environment and Natural Resources
Office of Waste Management
523 East Capital Avenue
Pierre, SD 57501
605-773-3351

TENNESSEE
Environment and Conservation Dept.
Solid Waste Management Division
401 Church Street, 5th Floor
Nashville, TN 37243-1535
615-532-0780

TEXAS
Natural Resource Conservation Commission
Industrial and Hazardous Waste Division
P.O. Box 13087
Capital Station
Austin, TX 78711-3087
512-239-2334

UTAH
Dept. of Environmental Quality
Division of Solid and Hazardous Waste
P.O. Box 144880
Salt Lake City, UT 84114-4880
801-538-6170

VERMONT
Natural Resources Agency
Environmental Conservation Dept.
Waste Management
West Office Building
103 South Main Street
Waterbury, VT 05671-0404
802-241-3888

VIRGINIA
Natural Resources Office
Environment Quality Dept.
629 East Main Street
Richmond, VA 23219
804-698-4020
Hazardous Waste Hotline: 800-552-2075

WASHINGTON
Dept. of Ecology
Solid and Hazardous Waste Program
P.O. Box 47600
Olympia, WA 98504-7600
360-407-6103

WEST VIRGINIA
Environmental Protection Bureau
Waste Management Division
1356 Hansford Street
Charleston, WV 25301
304-558-5929

WISCONSIN
Dept. of Natural Resources
Solid and Hazardous Waste Management
P.O. Box 7921
101 S Webster Street
Madison, WI 53707
608-266-1327

WYOMING
Dept. of Environmental Quality
Solid Waste Management Division
Herschler Building
122 West 25th Street
Cheyenne, WY 82002
307-777-7752

APPENDIX D

EPA REGIONAL OFFICES

EPA Region 1
JFK Federal Building
1 Congress Street
Boston, MA 02203
(617) 565-3420

Connecticut, Massachusetts, Maine, New Hampshire, Rhode Island, Vermont

EPA Region 2
290 Broadway
New York, NY 10007-1866
(212) 637-5000

New Jersey, New York, Puerto Rico, Virgin Islands

EPA Region 3
841 Chestnut Street
Philadelphia, PA 19107
(215) 597-9800

Delaware, District of Columbia, Maryland, Pennsylvania, Virginia, West Virginia

EPA Information on the World Wide Web:
http://www.epa.gov

EPA Region 4
345 Courtland Street NE
Atlanta, GA 30365
(404) 347-4727

Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee

EPA Region 5
77 West Jackson Blvd.
Chicago, IL 60604
(312) 353-2000

Illinois, Indiana, Michigan, Minnesota, Ohio, Wisconsin

EPA Region 6
1445 Ross Avenue
Dallas, TX 75202-2733
(214) 655-6548

Arkansas, Louisiana, New Mexico, Oklahoma, Texas

EPA Region 7
726 Minnesota Avenue
Kansas City, KS 66101
(913) 551-7000

Iowa, Kansas, Missouri, Nebraska

EPA Region 8
One Denver Place
999 18th Street
Denver, CO 80202-2406
(303) 312-6312

Colorado, Montana, North Dakota, South Dakota, Utah, Wyoming

EPA Region 9
75 Hawthorne Street
San Francisco, CA 94105
(415) 744-1305

Arizona, California, Hawaii, Nevada, American Samoa, Guam, Trust Territories of the Pacific

EPA Region 10
1200 Sixth Avenue
Seattle, WA 98101
(206) 553-1200

Alaska, Idaho, Oregon, Washington

ADDITIONAL SOURCES OF INFORMATION

Phone & Hotline Information

- RCRA/Superfund Hotline
  1-800-424-9346 (in Washington, DC 260-3000)

- Safe Drinking Water Act Hotline
  1-800-426-4791

- EPA Small Business Ombudsman Hotline
  1-800-368-5888 (in Washington, DC 557-1938)

- National Response Center
  1-800-494-8802 (in Washington, DC 260-2675)

- Transportation of Hazardous Materials
  202-366-4488

- Toxic Substances Control Act (TSCA) Assistance Service
  202-554-1404

- Center for Hazardous Materials Research (CHMR) Hotline
  1-800-334-2467

APPENDIX E

CHEMICAL AND PHYSICAL PROPERTIES OF PETROLEUM HYDROCARBONS

Fuels and waste oils will partition by volatilization, dissolution, or adsorption of individual components depending on their physical and chemical properties. The fate and transport of fuels and waste oils during biopile treatment depend mainly on their vapor pressure, water solubility, and Henry's law constant (U.S. Department of Health & Human Services, 1993a,b,c). Physical and chemical data for some types of fuel and oil components are illustrated in Figure E-1 and listed in Table E-1.

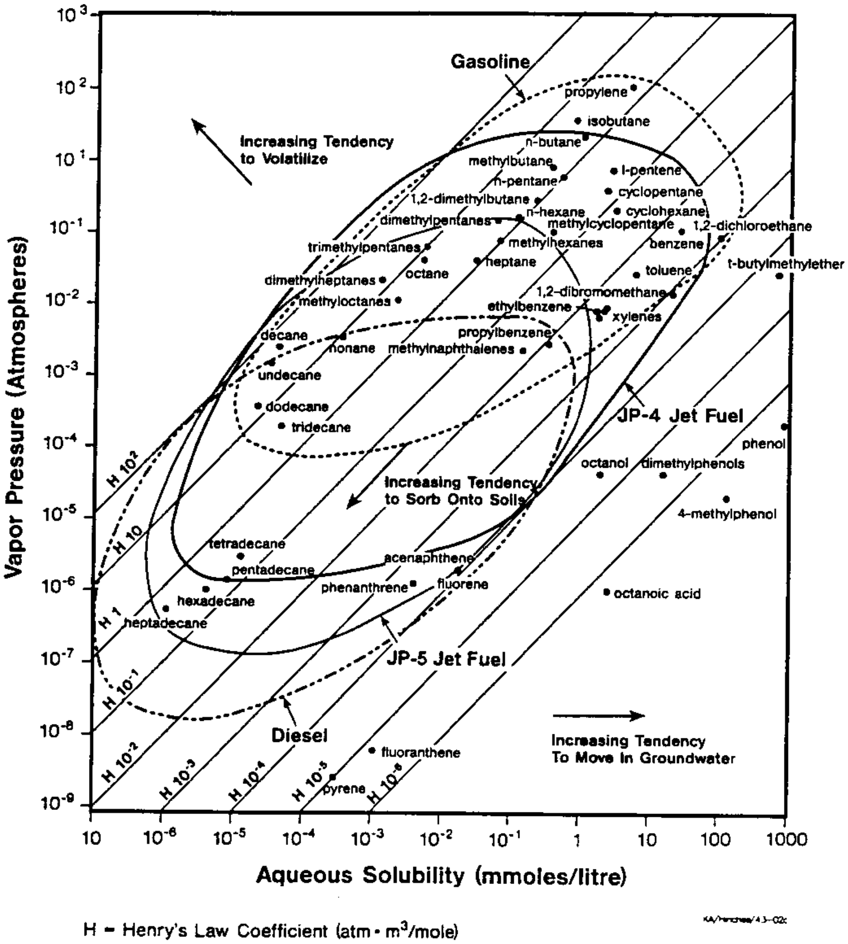


Figure E-1. Illustration of the Effect of the Properties of Fuel Components on In Situ Transport.

Table E-1. Properties of Example Components of Fuels and Waste Oils

emical Class	Compound	Formula	Molecular Weight	Density mg/L (at °C)	Melting Point (°C)	Boiling Point (°C)	Vapor Pressure mm Hg (at °C)	Solubility in Water mg/L (at °C)
es	*n*-Butane	$CH_3CH_2CH_2CH_3$	58.12	0.600 (0)	-135	-0.6	760 (-0.5)	61.4 (25)
	n-Pentane	$CH_3(CH_2)_3CH_3$	72.15	0.630 (18)	-129.7	36.3	400 (18.5)	40 (25)
	2-Methylpentane	$CH_3(CH_2)_2CH(CH_3)_2$	86.18	0.653$^{(a)}$	-154	62	200 (24.1)	14 (25)
	n-Hexane	$CH_3(CH_2)_4CH_3$	86.17	0.659 (20)	-94	69	100 (15.8)	10 (25)
	2-Methylhexane	$CH_3(CH_2)_3CH(CH_3)_2$	100.21	0.679$^{(a)}$	-118	90	60 (23)	2 (25)
	3-Methylhexane	$CH_3(CH_2)_2CH(CH_3)CH_2CH_3$	100.21	0.687$^{(a)}$	-119	91	60 (24.5)	4 (25)
	n-Heptane	$CH_3(CH_2)_5CH_3$	100.20	0.684 (20)	-90.6	98.4	40 (22.3)	3 (25)
	2-Methylheptane	$CH_3(CH_2)_4CH(CH_3)_2$	114.23	0.698$^{(a)}$	No data	116	20 (24.4)	No data
	3-Methylheptane	$CH_3(CH_2)_3CH(CH_3)CH_2CH_3$	114.23	No data	-120.5	115	20 (25.4)	0.8 (25)
	n-Octane	$CH_3(CH_2)_6CH_3$	114.22	0.703 (20)	-56.5	125.7	10 (19.2)	0.6 (25)
	n-Undecane	$CH_3(CH_2)_9CH_3$	156.30	0.741 (20)	-25.6	194.5	1 (32.7)	0.04 (25)
	n-Dodecane	$CH_3(CH_2)_{10}CH_3$	170.33	0.751 (20)	-9.6	214.5	1 (47.8)	0.004 (25)
	n-Tetradecane	$CH_3(CH_2)_{12}CH_3$	198.38	0.765 (20)	5.5	252.5	1 (76.4)	0.002 (25)
alkanes	Methylcyclopentane	$C_5H_9CH_3$	84.16	0.749$^{(a)}$	-142	72	100 (17.9)	42 (25)
	Cyclohexane	$CH_2(CH_2CH_2)_2CH_2$	84.16	0.779 (20)	6.5	80 - 81	100 (25.5)	60 (25)
	Methylcyclohexane	$CH_2(CH_2CH_2)_2CHCH_3$	98.18	0.769 (20)	-126.3	101	40 (22)	14 (25)
	n-Butylcyclohexane	$C_6H_{11}(CH_2)_3CH_3$	140.27	0.818$^{(a)}$	-78	178 - 180	No data	No data
enzenes	Benzene	C_6H_6	78.11	0.880 (20)	5.5	80.1	76 (20)	1,800 (20)
	Toluene	$C_6H_5CH_3$	92.10	0.870 (20)	-95.1	110.6	22 (20)	640 (25)
	Ethylbenzene	$C_6H_5C_2H_5$	106.17	0.867 (20)	-94.4	136.2	10 (25.9)	100 (15)
	o-Xylene	$C_6H_4(CH_3)_2$	106.17	0.881 (20)	-25	144.4	5 (20)	187 (25)
	m-Xylene	$C_6H_4(CH_3)_2$	106.17	0.861 (20)	-47.3	139.3	6 (20)	166 (25)
	p-Xylene	$C_6H_4(CH_3)_2$	106.17	0.864 (20)	13	138.4	6.5 (20)	175 (25)
	1,2,4-Trimethylbenzene	$C_6H_3(CH_3)_3$	120.19	0.876 (20)	-44	169 - 171	1 (13.6)	i$^{(b)}$
	1,3,5-Trimethylbenzene	$C_6H_3(CH_3)_3$	120.19	0.865 (20)	-45, -52	164.8	1 (9.6)	i$^{(b)}$
thalenes	Naphthalene	$C_{10}H_8$	128.16	1.145 (20)	80.2	217.9	0.0082 (25)	30 (25)
	1-Methylnaphthalene	$C_{10}H_7CH_3$	142.19	1.025 (14)	-19	244.6	No data	i$^{(b)}$
	2-Methylnaphthalene	$C_{10}H_7CH_3$	142.19	0.994 (40)	35 - 36	241 - 242	No data	i$^{(b)}$

References for Appendix E

Dean, J.A. 1992. *Lange's Handbook of Chemistry*, 14th ed. McGraw-Hill, New York, NY.

Lide, D.R., and H.P.R. Frederikse (Eds.). 1993. *CRC Handbook of Chemistry and Physics*, 74th ed. CRC Press, Boca Raton, FL.

Mackay, D., and W.Y. Shiu. 1981. “A Critical Review of Henry's Law Constants for Chemicals of Environmental Interest.” *J. Phys. Chem. Ref. Data, 10* (4):1175.

Verschueren, K. 1983. *Handbook of Environmental Data on Organic Chemicals*, 2nd ed. Van Nostrand Reinhold Co., New York, NY.

APPENDIX F

COMPANIES DOING TREATABILITY STUDIES

A listing of examples of some companies providing treatability testing for biopile treatment is provided to assist the user in starting a search for an appropriate testing service. This listing is not an exhaustive review of all possible qualified services. **Inclusion on the list should in no way be interpreted as an endorsement of any of the companies.**

Battelle
Environmental Restoration Department
505 King Avenue
Columbus, Ohio 43201
(614) 424-4698

Biotrol, Inc.
10300 Valley View Road
Suite 107
Eden Prairie, Minnesota 55344
(612) 942-8032

Center for Environmental Microbiology
1660 Chicago Avenue
Suite M-2
Riverside, CA 92507
(909) 787-3405

Lawhon & Associates
6300 Proprietor’s Road
Worthington, Ohio 43085
(614) 436-8400

Microbe Inotech Laboratories, Inc.
12133 Bridgestone Square Drive
Saint Louis, MO 63044
(314) 344-3030

Organic Waste Systems
3155 Research Boulevard
Suite 104
Dayton, Ohio 45420
(513) 253-6888

Retec
9 Pond Lane
Concord, Massachusetts 01742
(508) 371-1422

Retec
1005 W 9th Avenue
Suite A
King of Prussia, Pennsylvania 19406
(610) 992-9950

Roy F. Weston
212 Frank West Circle
Stockton, California 95206
(209) 983-1340

Versar, Inc.
39830 Grant River
Novi, Michigan 48375
(703) 893-4106

Woods End Laboratory
Old Rome Road
Route 2
Box 1850
Mt. Vernon, Maine 04352
(207) 293-2453

APPENDIX G

METHODS OF DETERMINING FIELD CAPACITY

Field capacity (FC) is "...the amount of water held in the soil after the excess gravitational water has drained away [from a saturated soil] and after the rate of downward movement of water has materially decreased" (Klute, 1994). This definition assumes that (a) the soil is deep and permeable; (b) no evaporation occurs from the soil surface; and (c) no barriers to permeability occur at shallow depths in the soil. In other words it is the water left in the soil after extra water from rainfall or irrigation has drained from the area or drainage has slowed to a negligible rate. The field capacity of a soil can be determined by ASTM D2325 or ASTM 3152, or may be approximated by any of the methods described in G.1 through G.6.

G.1 In Situ Field Capacity. When soil is at its naturally driest condition, construct a watertight dike around the perimeter of the test zone, which could be a 10 ft × 10 ft area. Flood the soil surface of the test area with water if it is flat, but if the area slopes then use a sprinkler system to apply the water. Immediately following water application, cover the test area with an evaporation barrier. After 48 hours, take soil samples, at least 4 at each depth.

$$FC_w = M_w / M_s \qquad (1)$$

where: M_w = the mass of water added
M_s = the oven-dried mass of soil
FC_w = the field capacity by weight

or $$FC_v = FC_w \text{ X } r_b / r_w = M_w / V_a \, r_w \qquad (2)$$

where: FC_v = the field capacity by volume
V_a = the bulk soil volume
r_b = the bulk soil density
r_w = the density of water

This method is the best for determining FC.

G.2 Large Soil Core Method (Approximate). Obtain a soil core with a 16-gauge steel cylinder. Remove it carefully from the ground, trying to maintain natural sorting and packing. In a laboratory, place the cylinder, with bottom cover removed, on a more fine-grained, dry soil. Add water to the core surface until it infiltrates to the desired depth then let stand for 48 hours. Take samples and calculate the approximate FC using Equations 1 and 2.

G.3 Small Soil Core Method (Approximate). Take several soil cores from each soil depth at the test site. Maintain the natural structure. In the laboratory, trim the ends of the soil core until they are even with the retaining ring. Place the core and ring on the ceramic plate, rotating slightly to ensure good contact. Wet the soil by capillary rise over 12 hours. Slowly increase the water level until the entire core is submerged and saturated. Then remove the excess water using a pressure plate with pressure equal to 10 kPa. Continue draining water until no more flows from the pressure plate. Oven-dry the sample for 24 hours at 105°C. Calculate the water content on either a weight or volume basis.

G.4 Centrifuge Method (Approximate). Perform this determination in duplicate. Cover the screened area of the brass centrifuge cups with Whatman no. 2 filter paper. Place 30 g of air-dried soil that has been screened through a 2-mm sieve into each cup. Wet the samples from the bottom by placing them in water and letting them soak for a few hours. Load the wet samples into the centrifuge and as quickly as possible bring them to 2,468 revolutions / minute. Maintain this speed for 30 minutes. After centrifugation is finished, quickly transfer the soil to tared moisture cans and obtain the masses needed to calculate FC.

G.5 Field-Expedient Method (Approximate). Figure G-1 shows the steps to be followed to estimate field capacity by the field-expedient method.

FIELD-EXPEDIENT METHOD FOR ESTIMATING THE FIELD CAPACITY OF A SOIL

1. Cut the bottom off a 2-L bottle, cover and tape some sort of screening material to the top opening, and invert the bottle.
2. Fill the bottle half full with a sample of dry soil to be used in the biopile.
3. Weigh bottle with soil and record weight.
4. Add water to soil in bottle. Mix while adding and allow water to saturate soil. Be careful not to spill any of the soil slurry from bottle.
5. Cover the bottle to prevent evaporative losses.
6. Let bottle stand overnight with the screened top down to allow water to drain from soil.
7. Weigh bottle with wet soil and record weight.
8. Estimate amount of water required to reach field capacity:
   [(wet soil - dry soil) / dry soil] = lb water required to reach field capacity per lb soil.
   To convert lb of water to gal of water multiply lb of water by 8.36.

Figure G-1. Field-Expedient Method for Estimating the Field Capacity of a Soil.

G.6 Reference for Appendix G

Klute, A. (Ed.). 1994. *Methods of Soil Analysis, Part 1*. 2nd ed. American Society of Agronomy, Madison, WI.

APPENDIX H

BIOPILE COST ESTIMATOR© COST SHEETS FOR SAMPLE CASES

H.1 TEMPORARY BIOPILE SAMPLE COST ESTIMATES

Project Name: Sample Test
Site Location: Test Site
Date of Estimate: 6/9/96
Unit Cell Dimensions: 50 ft x 60 ft
Total Volume to be Treated: 500 yd^3
Number of Cells: 1 Cell(s)
Volume of Cell Size: 500 yd^3/cell
Projected Cycle Length: 4 months
Total Project Life: 4 months
Total Temporary Biopile Installation Costs: $29,973

OVA Rental ☐
OVA Purchase ☐
None ☒
Injection ☐
Extraction ☒

Item	Unit	Unit Cost	Quantity	Total Cost	Comments	Vendor
treated 4-inch x 4-inch x 8' lumber	each	$5.27	28	$147.56		Fifth Avenue Lumber
treated 2-inch x 4-inch x 8' lumber	each	$4.42	28	$123.76		Fifth Avenue Lumber
3/4-in x 6-in lag bolt w/ washer and nut to secure 4-in x 4-in beams	each	$1.72	56	$96.32		Columbus Fasteners
connecting brackets to join 4-inch x 4-inch beams	each	$0.52	56	$29.12		Columbus Hardware
60-mil 51-ft x 61-ft HDPE bottom liner	each	$1,500.00	1	$1,500.00		Racer
clean dirt or clay for 8-inch foundation	yd^3	$10.00	7.1	$71.00		Jones Fuel Company
4-inch flexible, slotted drainage	ft	$0.18	90	$16.20		Discount Drainage
4-inch end caps for drainage pipe	each	$10.22	3	$30.66		U.S. Plastics
2-inch schedule 40 PVC pipe	20 ft	$23.00	3	$69.00		U.S. Plastics
4-inch rubber unions to connect drainage pipe to PVC	each	$5.89	3	$17.67		Discount Drainage
2-inch PVC gate valves	each	$20.00	3	$60.00		Pipe-Valves Inc.
4-inch SCH 40 PVC threaded/slip coupling	each	$7.48	6	$44.88		U.S. Plastics
4-inch to 2-inch PVC reducing bushing	each	$25.15	3	$75.45		U.S. Plastics
2-inch PVC slip tee	each	$2.31	2	$4.62		U.S. Plastics
2-inch PVC slip elbow (will vary depending on site layout)	each	$2.51	2	$5.02		U.S. Plastics
2-inch SCH 40 PVC pipe (adjust as dictated by proximiy of pump)	20 ft	$23.48	8	$187.81		U.S. Plastics
20-gal heavy duty PVC water knockout tank	each	$151.75	1	$151.75		U.S. Plastics
point switch/alarm controller (level control)	each	$300.00	1	$300.00		Cole-Parmer
fiber-optic sensor (for level controller)	each	$215.00	1	$215.00		Cole-Parmer
1-inch SCH 40 PVC pipe (adjust as required to plumb)	20 ft	$10.99	1	$10.99		U.S. Plastics
500-gal water collection tank	each	$860.00	1	$860.00		Cole-Parmer
1-1/2 hp rotary positive displacement vacuum pump	each	$821.00	1	$821.00		Grainger
4" thick concrete pad (10' x 12') for storage shed	sq. ft.	$6.00	120	$720.00		General Maintenance & Eng. Co
storage shed to house pump and materials	each	$249.00	1	$249.00		Grainger
55-gal granular activated carbon drum	each	$496.00	2	$992.00		Carbtrol Corp
misc. PVC fittings to connect knockout tank, pump and carbon drums		$250.00	1	$250.00		estimate
20-mil 70-ft x 75-ft plastic sheeting (HDPE or qualified substitute)		$200.00	1	$200.00		estimate
1-inch x 3-inch x 8-ft furring grade wood	each	$2.56	28	$71.68		Fifth Avenue Lumber
5/16-inch x 3-inch hex head sheet metal screw	each	$0.10	150	$15.00		Dotter fastener
nylon rope, 5/16"	100 ft	$19.23	4	$76.92		Grainger
3/8-inch x 3-1/4-inch I bolt	each	$0.76	12	$9.12		Columbus Fasteners
Urea	50 lb bag	$9.00	58	$522.00		Lesco
Ammonium Phosphate, Dibasic	50 lb bag	$44.50	8	$356.00		Ashland Chemical
Potassium Sulfate	50 lb bag	$16.20		$0.00		Lesco
Superphosphate	50 lb bag	$5.75		$0.00		Lesco
water hoses with nozzles	each	$33.69	4	$134.76		Columbus Hardware
scoop for nutrient addition	1	$5.00	1	$5.00		K-Mart
scale to measure nutrients	each	$68.05	1	$68.05		Grainger
2 1/2-gal bucket for holding/distributing nutrients	each	$5.45	1	$5.45		Cole-Parmer
1/4-inch OD nylon tubing for monitoring points-green	50ft	$19.25	2	$38.50		Cole-Parmer
1/4-inch OD nylon tubing for monitoring points-red	50ft	$19.25	3	$57.75		Cole-Parmer
1/4-inch OD nylon tubing for monitoring points-blue	50ft	$19.25	3	$57.75		Cole-Parmer
Thermocouple display, hand held	each	$75.00	1	$75.00		
K-type thermocouple wire, 24-gauge	100 ft roll	$48.50	1	$48.50		Cole-Parmer
K-type thermocouple plug	each	$3.18	10	$31.80		LH Marshall
NPT 3/8 X 1/4 tube fitting	each	$1.31	10	$13.10		Forberg Scientific
female quick-connect	each	$12.10	13	$157.30		Forberg Scientific
gravel for strainer	50 lb	$20.00	1	$20.00		estimate aquarium supply
suction strainer 3/4"	each	$9.49	10	$94.90		Grainger
3/8" thread tap	each	$6.32	10	$63.20		Columbus Hardware
male quick connect X 1/4 " tubing	each	$11.88	13	$154.44		Forberg Scientific
quick-connect protectors	each	$5.01	13	$65.13		Forberg Scientific
shovel	each	$20.95	2	$41.90		Grainger
1/3 HP sump pump	each	$131.78	1	$131.78		U.S. Plastics
1/3 HP transfer pump	each	$240.50	1	$240.50		Grainger
Gas Tech 3250X O2/CO2	each	$3,700.00	1	$3,700.00		Control Analytics
Gas Tech GT105 O2/TPH	each	$1,548.75	1	$1,548.75		Control Analytics
OVA		$0.00	1	$0.00	None	Hazco
Soil Compaction: technician	hour	$55.00	16	$880.00	Labor	
Berm and liner installation: technician	hour	$55.00	48	$2,640.00	Labor	
Berm and liner instalation supervision: supervisor	hour	$80.00	24	$1,920.00	Labor	
Knockout tank installation: technician	hour	$55.00	16	$880.00	Labor	
Transpt/instl leachate collection tank: laborer	hour	$20.00	16	$320.00	Labor	
install blower w/ variable speed process control: electrician	hour	$75.00	6	$450.00	Labor	
install knockout tank liquid level controller: electrician	hour	$75.00	6	$450.00	Labor	
soil pile construction: loader operator	hour	$55.00	16	$880.00	Labor	
soil pile construction: technician	hour	$55.00	80	$4,400.00	Labor	
soil pile construction: supervisor	hour	$80.00	20	$1,600.00	Labor	
soil pile construction: admin support staff	hour	$25.00	20	$500.00	Labor	

Installation Cost: **$29,973.09**

H.1 TEMPORARY BIOPILE SAMPLE COST ESTIMATES (Continued)

Operation and Maintenance Costs

Temporary Biopile Installation Total O&M Cost: $21,770.00

O&M Labor Cost Per Cell

Task	Unit	Unit Cost	Project Life	Hours	Total Cost
Initial project meeting: supervisor	Hour	$80.00		4	$320.00
Initial project meeting: technician	Hour	$55.00		8	$440.00
System startup: technician	Hour	$55.00		12	$660.00
System startup: supervisor	Hour	$80.00		4	$320.00
Weekly inspection (16 hr/mon): technician	Hour	$55.00	4	64	$3,520.00
Record keeping: supervisor (4 hr/mon)	Hour	$80.00	4	16	$1,280.00
Grounds keeping (8 hr/mon): laborer	Hour	$20.00	4	32	$640.00
Admin support (8 hr/mon): clerical	Hour	$25.00	4	32	$800.00
Respiration Test(16 hr/test): technician	Hour	$55.00	4	32	$1,760.00
Soil Sampling (6 hr/event): technician	Hour	$55.00	4	32	$1,760.00
Site closeout: loader operator	Hour	$55.00		16	$880.00
Site closeout: technician	Hour	$55.00		48	$2,640.00
Site closeout: supervisor	Hour	$80.00		24	$1,920.00
O&M Labor Cost Subtotal Per Cell					**$16,940.00**

Soil Sampling: 2 /cycle/cell
Soil Gas Sampling: 4 /cycle/cell
Respiration Test: 2 /cycle/cell

Total Analysis Cost $4,830.00

Sampling Cost Per Cell for 1 Cycle

Item	Unit	Unit Cost	Quantity	Cost/Event	Cost/Cycle
Analysis: soil fuel scan	event	$240.00	5	$1,200.00	$2,400.00
Analysis: soil BTEX	event	$95.00	5	$475.00	$950.00
Analysis: % moisture	event	$24.00	5	$120.00	$240.00
Analysis: heterotrophic plate count	event	$30.00	5	$150.00	$300.00
Anaylsis: soil pH	event	$18.00	5	$90.00	$180.00
Analysis: soil gas	event	$190.00	1	$190.00	$760.00
Analysis Subtotal Per Cell for 1 Cycle					**$4,830.00**

Subsequent Biopile Construction Cost **$0.00**

Biopile System Cost Summary

Project Name:	Sample Test
Location:	Test Site
Date of Estimate:	6/9/96

Total Volume to be Treated	500 yd^3
Number of Cells	1 cell(s)
Volume of Cell Size	500 yd^3/cell
Number of Cycles	1 cycles
Expected Project Life, months	4 months

Total Temporary Biopile Installation Cost	$29,973.09
Total O&M Cost	$21,770.00

Present Value of Annual Costs

Inflation Rate 0.035

Inflation-Adjusted Average Annual Costs (Out-Years)	NA
TOTAL COST ESTIMATE	**$51,744**
Unit Cost ($/$yd^3$)	**$103.49**

Comments:

Biopile System Cost Summary

Project Name: Sample Test
Location: Test Site
Date of Estimate: 6/9/96

Total Volume to be Treated	1000 yd^3
Number of Cells	1 cell(s)
Volume of Cell Size	500 yd^3/cell
Number of Cycles	2 cycles
Expected Project Life, months	8 months

Total Temporary Biopile Installation Cost	$29,973.09
Total O&M Cost	$45,610.00

Present Value of Annual Costs

Inflation Rate 0.035

Inflation-Adjusted Average Annual Costs (Out-Years)	NA
TOTAL COST ESTIMATE	**$75,584**
Unit Cost ($/$yd^3$)	**$75.58**

Comments:

Biopile System Cost Summary

Project Name: Sample Test
Location: Test Site
Date of Estimate: 6/9/96

Total Volume to be Treated	2000 yd^3
Number of Cells	1 cell(s)
Volume of Cell Size	500 yd^3/cell
Number of Cycles	4 cycles
Expected Project Life, months	16 months

Total Temporary Biopile Installation Cost	$29,973.09
Total O&M Cost	$93,290.00

Present Value of Annual Costs

Inflation Rate 0.035

Inflation-Adjusted Average Annual Costs (Out-Years)	$96,555.15
TOTAL COST ESTIMATE	**$126,529**
Unit Cost ($/yd^3)	**$63.26**

Comments:

Biopile System Cost Summary

Project Name:	Sample Test
Location:	Test Site
Date of Estimate:	6/9/96

Total Volume to be Treated	2000 yd^3
Number of Cells	2 cell(s)
Volume of Cell Size	500 yd^3/cell
Number of Cycles	2 cycles
Expected Project Life, months	8 months

Total Temporary Biopile Installation Cost	$50,558.87
Total O&M Cost	$88,850.00

Present Value of Annual Costs

Inflation Rate 0.035

Inflation-Adjusted Average Annual Costs (Out-Years)	NA
TOTAL COST ESTIMATE	**$139,409**
Unit Cost ($/$yd^3$)	**$69.70**

Comments:

Biopile System Cost Summary

Project Name: Sample Test
Location: Test Site
Date of Estimate 6/9/96

Total Volume to be Treated	5000 yd^3
Number of Cells	1 cell(s)
Volume of Cell Size	500 yd^3/cell
Number of Cycles	10 cycles
Expected Project Life, mont	40 months

Total Temporary Biopile Installation Cost	$29,973.09
Total O&M Cost	$236,330.00

Present Value of Annual Costs

Inflation Rate 0.035

Inflation-Adjusted Average Annual Costs (Out-Year	$253,262.48
TOTAL COST ESTIMATE	**$283,236**
Unit Cost ($/yd^3)	**$56.65**

Comments:

Biopile System Cost Summary

Project Name: Sample Test
Location: Test Site
Date of Estimate 6/9/96

Total Volume to be Treated	5000 yd^3
Number of Cells	1 cell(s)
Volume of Cell Size	750 yd^3/cell
Number of Cycles	7 cycles
Expected Project Life, mont	28 months

Total Temporary Biopile Installation Cost	$29,973.09
Total O&M Cost	$164,810.00

Present Value of Annual Costs

Inflation Rate	0.035	
Inflation-Adjusted Average Annual Costs (Out-Year		$173,563.47
TOTAL COST ESTIMATE		**$203,537**
Unit Cost (\$/yd^3)		**$40.71**

Comments:

Biopile System Cost Summary

Project Name: Sample Test
Location: Test Site
Date of Estimate: 6/9/96

Total Volume to be Treated	5000 yd^3
Number of Cells	2 cell(s)
Volume of Cell Size	500 yd^3/cell
Number of Cycles	5 cycles
Expected Project Life, months	20 months

Total Temporary Biopile Installation Cost		$50,558.87
Total O&M Cost		$224,780.00
Present Value of Annual Costs		
Inflation Rate	0.035	
Inflation-Adjusted Average Annual Costs (Out-Years)		$232,647.30
TOTAL COST ESTIMATE		**$283,207**
Unit Cost (\$/yd^3)		**$56.64**

Comments:

Biopile System Cost Summary

Project Name:	Sample Test
Location:	Test Site
Date of Estimate:	6/9/96

Total Volume to be Treated	5000 yd^3
Number of Cells	2 cell(s)
Volume of Cell Size	750 yd^3/cell
Number of Cycles	4 cycles
Expected Project Life, months	16 months

Total Temporary Biopile Installation Cost	$50,558.87
Total O&M Cost	$174,640.00

Present Value of Annual Costs

Inflation Rate 0.035

Inflation-Adjusted Average Annual Costs (Out-Years)	$180,752.40
TOTAL COST ESTIMATE	**$231,312**
Unit Cost ($/yd^3)	**$46.26**

Comments:

H.2 PERMANENT BIOPILE SAMPLE COST ESTIMATES

Permanent Biopile Installation

Project Name: Sample Test
Location: Test Site
Date of Estimate: 6/9/96
Total Volume to be Treated: 500 yd^3
Number of Cells: 1 Cell(s)
Volume of Cell Size: 500 yd^3/cell
Projected Cycle Length: 4 months
Total Project Length: 4 months
Total Permanent Biopile Installation Costs: $76,725

Unit Cell Dimensions: 50 ft x 60 ft

OVA Rental ☒
OVA Purchase ☐
None ☐
Injection ☐
Extraction ☒

Item	Unit	Unit Cost	Quantity	Total Cost	Comments	Vendor
60-mil geotextile HDPE liner 55' x 65'	each	$9,435.54	1	$9,435.54	installed w/ compacted soil base	Racer
2-inch flexible, slotted PVC	ft	$0.18	90	$16.20		Discount Drainage
2-inch end caps for drainage pipe	each	$10.22	3	$30.66		U.S. Plastics
2-inch schedule 40 PVC pipe	20 ft	$69.00	1.5	$103.50		U.S. Plastics
2"- 4" rubber reducer	each	$5.89	3	$17.67		Discount Drainage
2-inch brass gate valves	each	$417.33	3	$1,251.99		Pipe-Valves Inc.
2-inch galvanized steel pipe SCH 40	10 ft	$25.20	1	$25.20		Pipe-Valves Inc.
2-inch PVC slip tee	each	$2.31	2	$4.62		U.S. Plastics
2-inch PVC slip elbow (will vary depending on site layout)	each	$2.51	2	$5.02		U.S. Plastics
2-inch SCH 40 PVC pipe (adjust as dictated by proximiy of pump)	20 ft	$23.48	8	$187.81		U.S. Plastics
20-gal heavy duty PVC water knockout tank	each	$151.75	1	$151.75		U.S. Plastics
point switch/alarm controller (level control)	each	$300.00	1	$300.00		Cole-Parmer
fiber-optic sensor (for level controller)	each	$215.00	1	$215.00		Cole-Parmer
1-inch SCH 40 PVC pipe (adjust as required to plumb)	20 ft	$10.99	1	$10.99		U.S. Plastics
500-gal water collection tank	each	$860.00	1	$860.00		Cole-Parmer
1-1/2 hp rotary centrifugal vacuum pump	each	$821.00	1	$821.00		Grainger
4" thick concrete pad (10' x 12') for storage shed	sq. ft	$6.00	120	$720.00		General Maintenance & Eng. Co.
storage shed to house pump and materials	each	$249.00	1	$249.00		Grainger
55-gal granular activated carbon drum	each	$496.00	2	$992.00		Carbtrol Corp
misc. PVC fittings to connect knockout tank, pump and carbon drums		$250.00	1	$250.00		estimate
20-mil 70-ft x 75-ft plastic sheeting (HDPE or qualified substitute)	each	$200.00	1	$200.00		Racer
5/16-inch x 3-inch hex head sheet metal screw	each	$0.10	150	$15.00		Dotter fastener
nylon rope, 5/16"	100 ft	$19.23	4	$76.92		Grainger
Urea	50 lb bag	$9.00	58	$522.00		Lesco
Ammonium Phosphate, Dibasic	50 lb bag	$44.50	8	$356.00		Ashland Chemical
Potassium Sulfate	50 lb bag	$16.20		$0.00		Lesco
Superphosphate	50 lb bag	$5.75		$0.00		Lesco
water hoses with nozzles	each	$33.69	4	$134.76		Columbus Hardware
scoop for nutrient addition	each	$5.00	1	$5.00		K-Mart
scale to measure nutrients	each	$68.05	1	$68.05		Grainger
2 1/2-gal bucket for holding/distributing nutrients	each	$5.45	1	$5.45		Cole-Parmer
1/4-inch OD nylon tubing for monitoring points-green	50ft	$19.25	3	$57.75		Cole-Parmer
1/4-inch OD nylon tubing for monitoring points-red	50ft	$19.25	3	$57.75		Cole-Parmer
1/4-inch OD nylon tubing for monitoring points-blue	50ft	$19.25	3	$57.75		Cole-Parmer
Thermocouple display, hand held	each	$65.00	1	$65.00		Cole-Parmer
K-type thermocouple wire, 24-gauge	100 ft roll	$48.50	1	$48.50		Cole-Parmer
K-type thermocouple plug	each	$3.18	10	$31.80		LH Marshall
NPT 3/8 X 1/4 tube fitting	each	$1.31	10	$13.10		Forberg Scientific
female quick-connect	each	$12.10	13	$157.30		Forberg Scientific
gravel for strainer	50 lb	$20.00	1	$20.00		estimate aquarium supply
suction strainer 3/4"	each	$9.49	10	$94.90		Grainger
3/8" thread tap	each	$6.32	10	$63.20		Columbus Hardware
male quick connect X 1/4 " tubing	each	$11.88	13	$154.44		Forberg Scientific
quick-connect protectors	each	$5.01	13	$65.13		Forberg Scientific
shovel	each	$20.95	2	$41.90		Grainger
1/3 HP sump pump	each	$131.78	1	$131.78		U.S. Plastics
1/3 HP transfer pump	each	$240.50	1	$240.50		Grainger
Aeration/Leachate Collection Channel	each	$3,294.58	1	$3,294.58		Racer
8" Structural Slab on grade	each	$33,499.01	1	$33,499.01		Racer
Gas Tech 3250X O_2/CO_2	each	$3,700.00	1	$3,700.00		Control Analytics
Gas Tech GT105 O_2/TPH	each	$1,548.75	1	$1,548.75		Control Analytics
OVA	weekly	$477.00	3	$1,431.00	Rental	Hazco
Soil Compaction: technician	hour	$55.00	16	$880.00	Labor	
Berm and liner installation: technician	hour	$55.00	48	$2,640.00	Labor	
Berm and liner instalation supervision: supervisor	hour	$80.00	24	$1,920.00	Labor	
Knockout tank installation: technician	hour	$55.00	16	$880.00	Labor	
Transpt/instl leachate collection tank: laborer	hour	$20.00	16	$320.00	Labor	
install blower w/ variable speed process control: electrician	hour	$75.00	6	$450.00	Labor	
install knockout tank liquid level controller: electrician	hour	$75.00	6	$450.00	Labor	
soil pile construction: loader operator	hour	$55.00	16	$880.00	Labor	
soil pile construction: technician	hour	$55.00	80	$4,400.00	Labor	
soil pile construction: supervisor	hour	$80.00	20	$1,600.00	Labor	
soil pile construction: admin support staff	hour	$25.00	20	$500.00	Labor	

Installation Cost **$76,725.27**

Operation and Maintenance Costs

Permanent Biopile Installation

Total O&M Cost: **$21,770.00**

O&M Labor Cost Per Cell

Task	Unit	Unit Cost	Project Life	Hours	Total Cost
Initial project meeting: supervisor	Hour	$80.00		4	$320.00
Initial project meeting: technician	Hour	$55.00		8	$440.00
System startup: technician	Hour	$55.00		12	$660.00
System startup: supervisor	Hour	$80.00		4	$320.00
Weekly inspection (16 hr/mon): technician	Hour	$55.00	4	64	$3,520.00
Record keeping: supervisor (4 hr/mon)	Hour	$80.00	4	16	$1,280.00
Grounds keeping (8 hr/mon): laborer	Hour	$20.00	4	32	$640.00
Admin support (8 hr/mon): clerical	Hour	$25.00	4	32	$800.00
Respiration Test(16 hr/test): technician	Hour	$55.00	4	32	$1,760.00
Soil Sampling (6 hr/event): technician	Hour	$55.00	4	32	$1,760.00
Site closeout: loader operator	Hour	$55.00		16	$880.00
Site closeout: technician	Hour	$55.00		48	$2,640.00
Site closeout: supervisor	Hour	$80.00		24	$1,920.00

O&M Labor Cost Subtotal Per Cell **$16,940.00**

Soil Sampling: 2 /cycle/cell
Soil Gas Sampling: 4 /cycle/cell
Respiration Test: 2 /cycle/cell

Total Analysis Cost **$4,830.00**

Sampling Cost Per Cell for 1 Cycle

Item	Unit	Unit Cost	Quantity	Cost/Event	Cost/Cycle
Analysis: soil fuel scan	event	$240.00	5	$1,200.00	$2,400.00
Analysis: soil BTEX	event	$95.00	5	$475.00	$950.00
Analysis: % moisture	event	$24.00	5	$120.00	$240.00
Analysis: heterotrophic plate count	event	$30.00	5	$150.00	$300.00
Anaylsis: soil pH	event	$18.00	5	$90.00	$180.00
Analysis: soil gas	event	$190.00	1	$190.00	$760.00

Analysis Subtotal Per Cell for 1 Cycle **$4,830.00**

Subsequent Biopile Construction Cost **$0.00**

Biopile System Cost Summary

Project Name: Sample Test
Location: Test Site
Date of Estimate: 6/9/96

Total Volume to be Treated	500 yd^3
Number of Cells	1 cell(s)
Volume of Cell Size	500 yd^3/cell
Number of Cycles	1 cycles
Expected Project Life, months	4 months

Total Permanent Biopile Installation Cost	$76,725.27
Total O&M Cost	$21,770.00

Present Value of Annual Costs

Inflation Rate 0.035

Inflation-Adjusted Average Annual Costs (Out-Years)	NA
TOTAL COST ESTIMATE	**$98,496**
Unit Cost ($/$yd^3$)	**$196.99**

Comments:

Biopile System Cost Summary

Project Name:	Sample Test
Location:	Test Site
Date of Estimate:	6/9/96

Total Volume to be Treated	5000 yd^3
Number of Cells	1 cell(s)
Volume of Cell Size	500 yd^3/cell
Number of Cycles	10 cycles
Expected Project Life, months	40 months

Total Permanent Biopile Installation Cost	$76,725.27
Total O&M Cost	$237,761.00

Present Value of Annual Costs

Inflation Rate	0.035
Inflation-Adjusted Average Annual Costs (Out-Years)	$254,796.01
TOTAL COST ESTIMATE	**$331,522**
Unit Cost ($/$yd^3$)	**$66.30**

Comments:

Biopile System Cost Summary

Project Name:	Sample Test
Location:	Test Site
Date of Estimate:	6/9/96

Total Volume to be Treated	5000 yd^3
Number of Cells	1 cell(s)
Volume of Cell Size	750 yd^3/cell
Number of Cycles	7 cycles
Expected Project Life, months	28 months

Total Permanent Biopile Installation Cost	$76,725.27
Total O&M Cost	$166,241.00

Present Value of Annual Costs

Inflation Rate 0.035

Inflation-Adjusted Average Annual Costs (Out-Years)	$175,070.48
TOTAL COST ESTIMATE	**$251,796**
Unit Cost ($/$yd^3$)	**$50.36**

Comments:

Biopile System Cost Summary

Project Name:	Sample Test
Location:	Test Site
Date of Estimate:	6/9/96

Total Volume to be Treated	10000 yd^3
Number of Cells	1 cell(s)
Volume of Cell Size	500 yd^3/cell
Number of Cycles	20 cycles
Expected Project Life, months	80 months

Total Permanent Biopile Installation Cost	$76,725.27
Total O&M Cost	$476,161.00

Present Value of Annual Costs

Inflation Rate 0.035

Inflation-Adjusted Average Annual Costs (Out-Years)	$538,014.91
TOTAL COST ESTIMATE	**$614,741**
Unit Cost ($/$yd^3$)	**$61.47**

Comments:

Biopile System Cost Summary

Project Name:	Sample Test
Location:	Test Site
Date of Estimate:	6/9/96

Total Volume to be Treated	10000 yd^3
Number of Cells	2 cell(s)
Volume of Cell Size	500 yd^3/cell
Number of Cycles	10 cycles
Expected Project Life, months	40 months

Total Permanent Biopile Installation Cost	$141,875.30
Total O&M Cost	$452,761.00

Present Value of Annual Costs

Inflation Rate 0.035

Inflation-Adjusted Average Annual Costs (Out-Years)	$485,200.25
TOTAL COST ESTIMATE	**$627,076**
Unit Cost ($/yd^3)	**$62.71**

Comments:

Biopile System Cost Summary

Project Name:	Sample Test
Location:	Test Site
Date of Estimate:	6/9/96

Total Volume to be Treated	20000	yd^3
Number of Cells	2	cell(s)
Volume of Cell Size	500	yd^3/cell
Number of Cycles	20	cycles
Expected Project Life, months	80	months

Total Permanent Biopile Installation Cost	$141,875.30
Total O&M Cost	$905,861.00

Present Value of Annual Costs

Inflation Rate 0.035

Inflation-Adjusted Average Annual Costs (Out-Years)	$1,023,533.48
TOTAL COST ESTIMATE	**$1,165,409**
Unit Cost (\$/yd^3)	**$58.27**

Comments:

Biopile System Cost Summary

Project Name: Sample Test
Location: Test Site
Date of Estimate: 6/9/96

Total Volume to be Treated	20000	yd^3
Number of Cells	4	cell(s)
Volume of Cell Size	500	yd^3/cell
Number of Cycles	10	cycles
Expected Project Life, months	40	months

Total Permanent Biopile Installation Cost	$274,386.35
Total O&M Cost	$909,545.00

Present Value of Annual Costs

Inflation Rate 0.035

Inflation-Adjusted Average Annual Costs (Out-Years)	$974,711.74
TOTAL COST ESTIMATE	**$1,249,099**
Unit Cost ($/yd^3)	**$62.45**

Comments:

Biopile System Cost Summary

Project Name: Sample Test
Location: Test Site
Date of Estimate: 6/9/96

Total Volume to be Treated	40000 yd^3
Number of Cells	4 cell(s)
Volume of Cell Size	750 yd^3/cell
Number of Cycles	14 cycles
Expected Project Life, months	56 months

Total Permanent Biopile Installation Cost	$274,386.35
Total O&M Cost	$1,264,789.00
Present Value of Annual Costs	
Inflation Rate	0.035
Inflation-Adjusted Average Annual Costs (Out-Years)	$1,379,399.71
TOTAL COST ESTIMATE	**$1,653,787**
Unit Cost ($/yd^3)	**$41.34**

Comments:

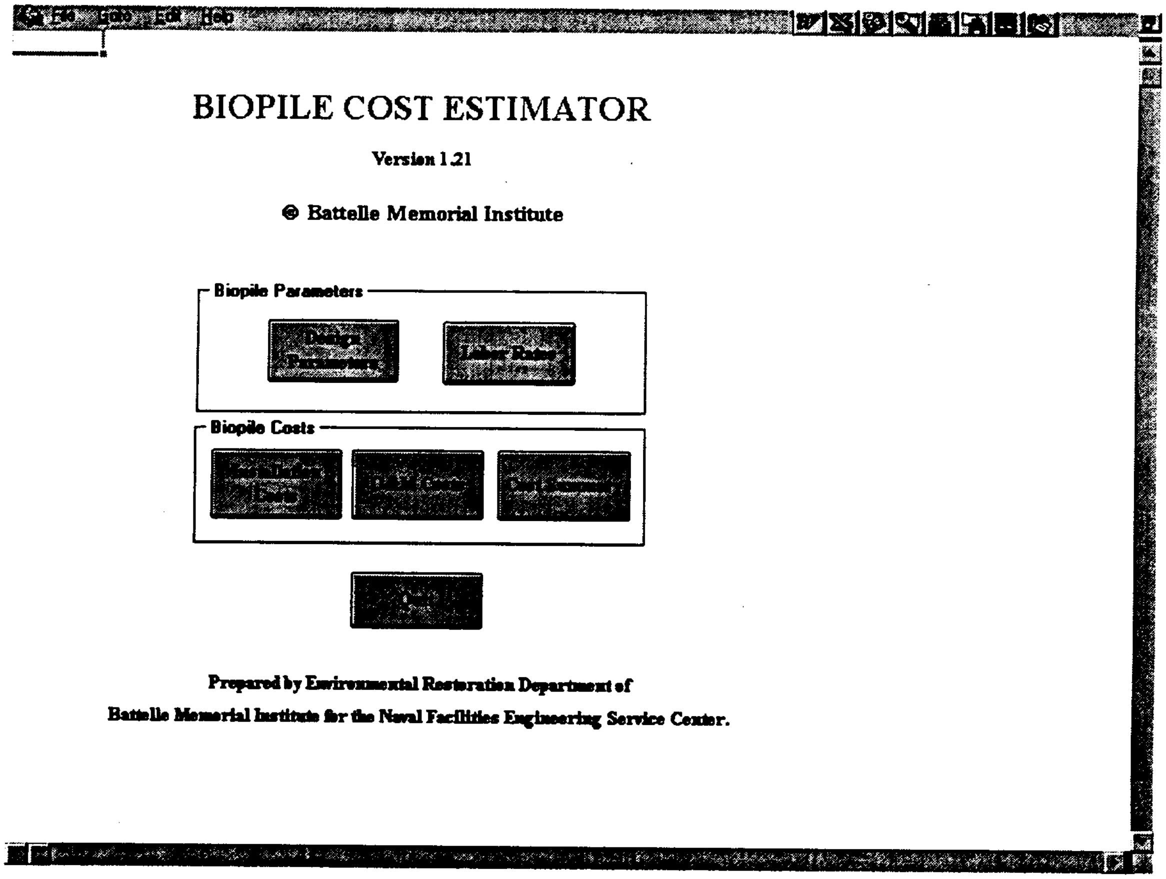
H.3 BIOPILE COST ESTIMATOR© INSTRUCTION GUIDE

Prepared by F. Michael von Fahnestock and Sam W. Yoon, Battelle, for Naval Facilities Engineering Service Center, May 29, 1996.

This instruction guide gives a visual overview of the Biopile Cost Estimator© software program used to generate the preceding cost sheets for the various biopile design scenarios. This program can be obtained from NFESC, located at 1100 23rd Avenue, Port Hueneme, CA, 93043-4301.

Main Menu

The main menu allows access to all input and report screens.



BIOPILE COST ESTIMATOR

Version 1.21

© Battelle Memorial Institute

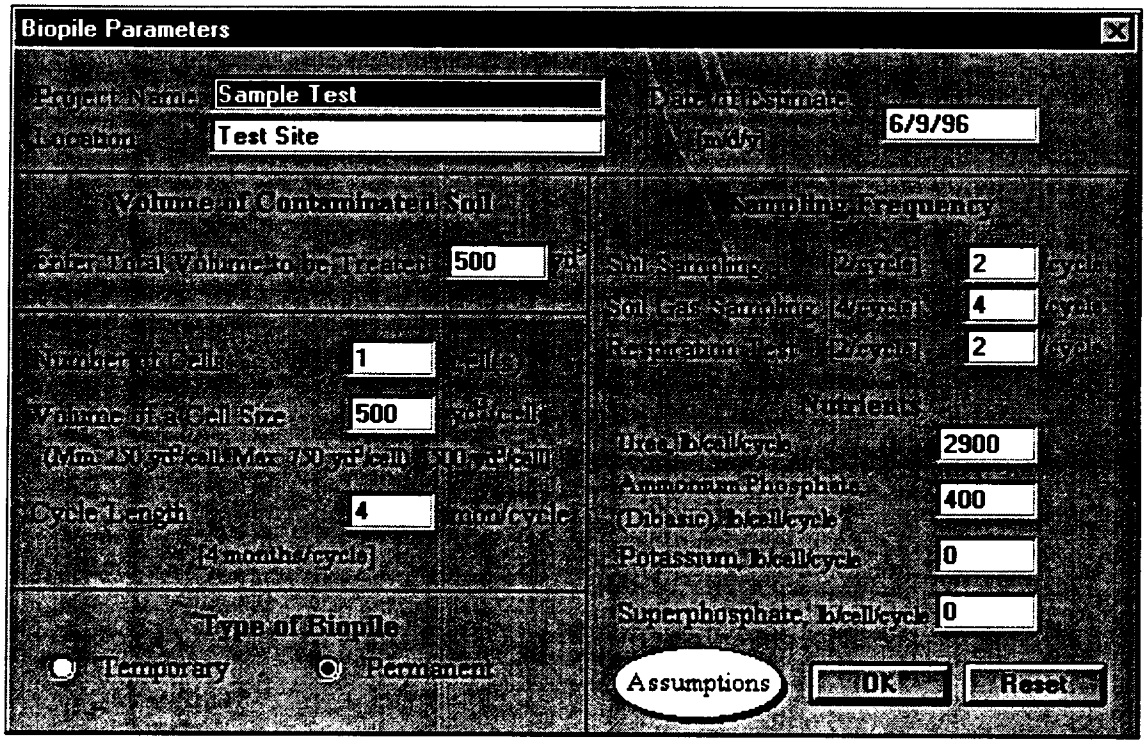
Prepared by Environmental Restoration Department of
Battelle Memorial Institute for the Naval Facilities Engineering Service Center.

Biopile Design Parameters

Click the **DESIGN PARAMETERS** button to reach the Biopile Parameters screen. Use this screen to input the design variables. Recommended default values are given in brackets. This window initially displays the values last saved in the program. Use the mouse or the tab key to move to the desired input field.

Click the **OK** button once all variables have been specified. The program will calculate the installation and O&M costs and will then automatically display the Installation Cost Table.

Click the **ASSUMPTIONS** button to list the general design assumptions used with this cost estimation tool.



Project Name: Sample Test

Location: Test Site

Date of Estimate (m/d/y): 6/9/96

Volume of Contaminated Soil

Enter Total Volume to be Treated: 500 yd³

Number of Cells: 1 cell(s)

Volume of a Cell Size: 500 yd³/cell

(Min 250 yd³/cell, Max 750 yd³/cell) [500 yd³/cell]

Cycle Length: 4 mon/cycle

[4 months/cycle]

Type of Biopile

○ Temporary ● Permanent

Sampling Frequency

Soil Sampling [2/cycle]: 2 /cycle

Soil Gas Sampling [4/cycle]: 4 /cycle

Respiration Test [2/cycle]: 2 /cycle

Nutrients

Urea, lb/cell/cycle: 2900

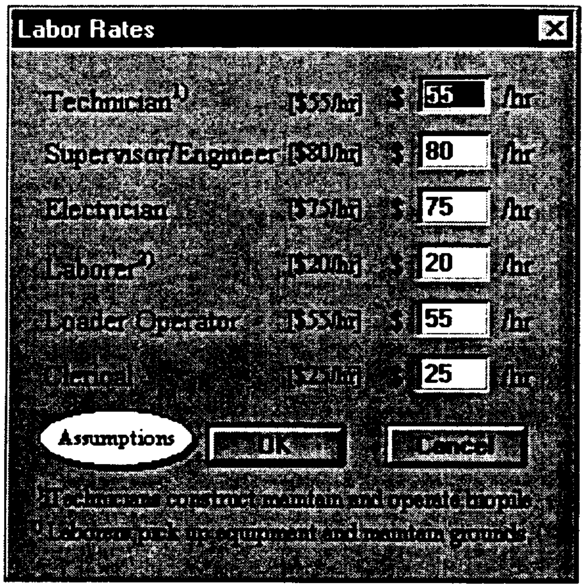
Ammonium Phosphate (Dibasic), lb/cell/cycle: 400

Potassium, lb/cell/cycle: 0

Superphosphate, lb/cell/cycle: 0

Labor Rates

The hourly rates for various labor categories can be adjusted to make the cost estimate site specific. To list the labor rate assumptions, click the **ASSUMPTIONS** button. Click the **OK** button to accept the labor rates entered and to forward to the Installation Cost Screen.



Technician[1) [$55/hr] $ 55 /hr
Supervisor/Engineer [$80/hr] $ 80 /hr
Electrician [$75/hr] $ 75 /hr
Laborer[2) [$20/hr] $ 20 /hr
Loader Operator [$55/hr] $ 55 /hr
Clerical [$25/hr] $ 25 /hr

[1) Technicians construct, maintain and operate biopile.
[2) Laborers pick up equipment and maintain grounds.

Note: Labor rates shown above are for this example case only. Actual rates should be entered on a site-specific basis.

Installation Cost Screen

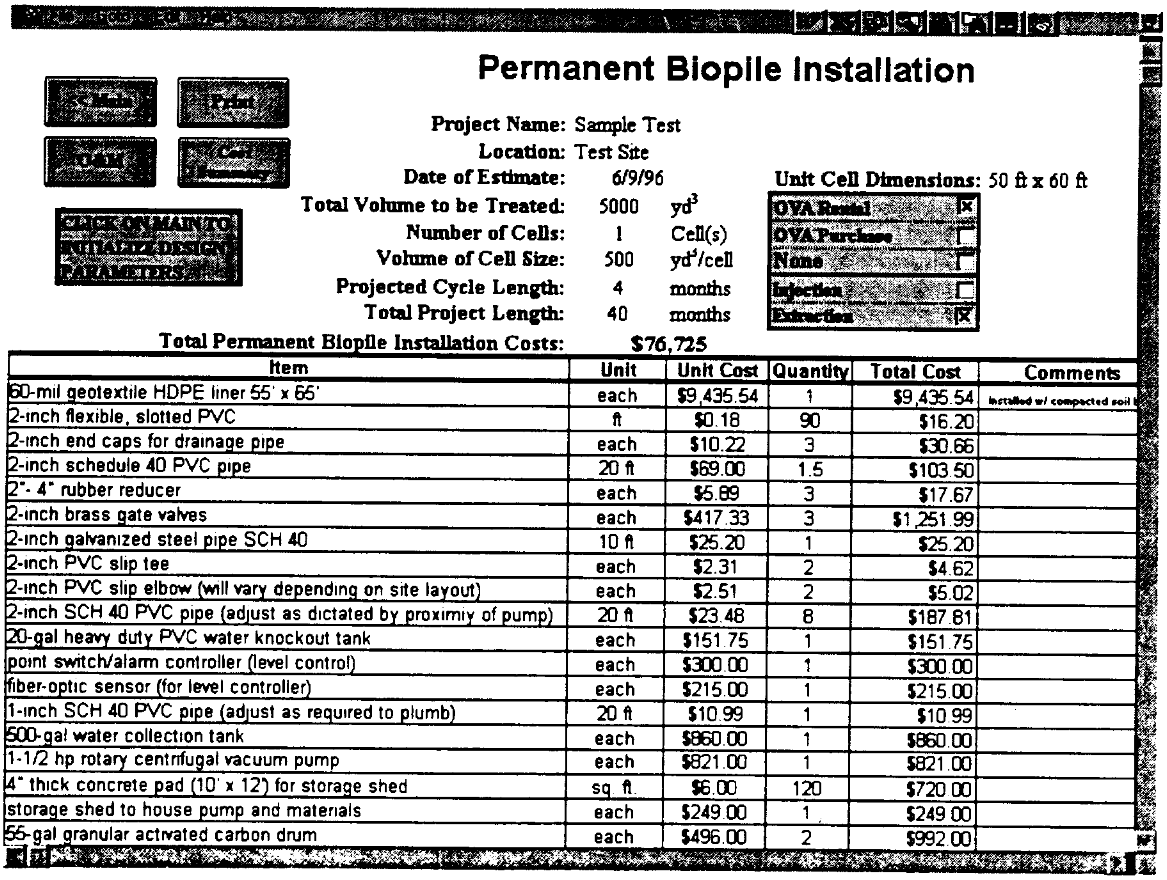
This screen lists installation costs for the biopile design selected on a 'per cell' basis. The table gives a line item cost breakout of all materials and equipment required.

Click the **MAIN** button to return to the main menu. To change design specifications, select the **DESIGN PARAMETERS** button from the main menu and reenter values as desired.

Click the **O&M COSTS** button to view the O&M Cost Screen.

Click the **SUMMARY COST** button to view the overall biopile design cost.

Click the **PRINT** button to produce a hard copy of the Installation Cost Screen.



Permanent Biopile Installation

Project Name: Sample Test
Location: Test Site
Date of Estimate: 6/9/96
Total Volume to be Treated: 5000 yd^3
Number of Cells: 1 Cell(s)
Volume of Cell Size: 500 yd^3/cell
Projected Cycle Length: 4 months
Total Project Length: 40 months
Unit Cell Dimensions: 50 ft x 60 ft

OVA Rental ☒
OVA Purchase ☐
None ☐
Injection ☐
Extraction ☒

Total Permanent Biopile Installation Costs: **$76,725**

Item	Unit	Unit Cost	Quantity	Total Cost	Comments
60-mil geotextile HDPE liner 55' x 65'	each	$9,435.54	1	$9,435.54	installed w/ compacted soil
2-inch flexible, slotted PVC	ft	$0.18	90	$16.20	
2-inch end caps for drainage pipe	each	$10.22	3	$30.66	
2-inch schedule 40 PVC pipe	20 ft	$69.00	1.5	$103.50	
2"- 4" rubber reducer	each	$5.89	3	$17.67	
2-inch brass gate valves	each	$417.33	3	$1,251.99	
2-inch galvanized steel pipe SCH 40	10 ft	$25.20	1	$25.20	
2-inch PVC slip tee	each	$2.31	2	$4.62	
2-inch PVC slip elbow (will vary depending on site layout)	each	$2.51	2	$5.02	
2-inch SCH 40 PVC pipe (adjust as dictated by proximiy of pump)	20 ft	$23.48	8	$187.81	
20-gal heavy duty PVC water knockout tank	each	$151.75	1	$151.75	
point switch/alarm controller (level control)	each	$300.00	1	$300.00	
fiber-optic sensor (for level controller)	each	$215.00	1	$215.00	
1-inch SCH 40 PVC pipe (adjust as required to plumb)	20 ft	$10.99	1	$10.99	
500-gal water collection tank	each	$860.00	1	$860.00	
1-1/2 hp rotary centrifugal vacuum pump	each	$821.00	1	$821.00	
4" thick concrete pad (10' x 12') for storage shed	sq. ft.	$6.00	120	$720.00	
storage shed to house pump and materials	each	$249.00	1	$249.00	
55-gal granular activated carbon drum	each	$496.00	2	$992.00	

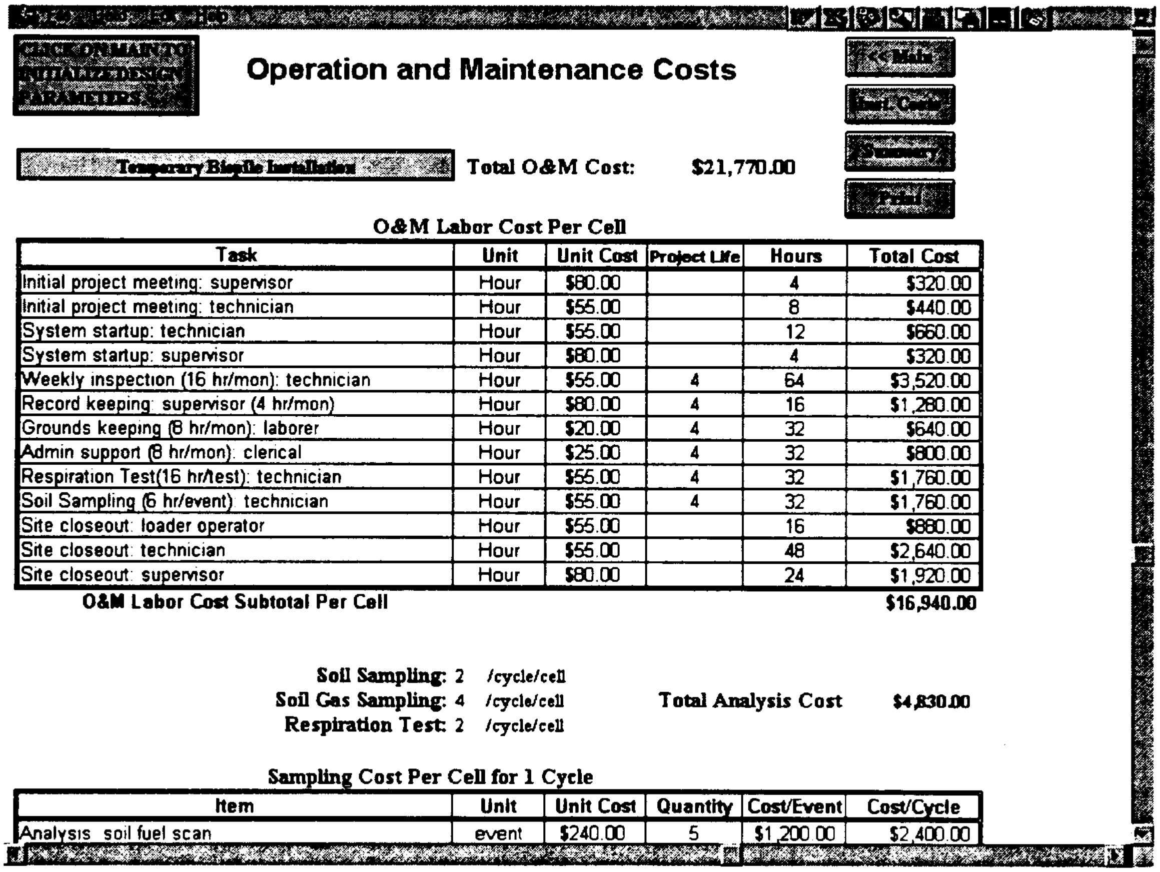
O&M Cost Screen

View the O&M Cost Screen by clicking the **O&M COSTS** button from the main menu, or by clicking the **O&M COSTS** button in the Installation Cost Screen, or the Summary Screen.

The O&M Cost Screen lists the total O&M cost estimate and sampling costs per cell. This screen also gives the total biopile cell reconstruction cost for sites requiring multiple cycles.

Return to the main menu or go to the Installation Cost or Summary Cost Screens by clicking the appropriate buttons.

Click **PRINT** to produce a hard copy of the O&M Cost Screen.



Operation and Maintenance Costs

Total O&M Cost: **$21,770.00**

O&M Labor Cost Per Cell

Task	Unit	Unit Cost	Project Life	Hours	Total Cost
Initial project meeting: supervisor	Hour	$80.00		4	$320.00
Initial project meeting: technician	Hour	$55.00		8	$440.00
System startup: technician	Hour	$55.00		12	$660.00
System startup: supervisor	Hour	$80.00		4	$320.00
Weekly inspection (16 hr/mon): technician	Hour	$55.00	4	64	$3,520.00
Record keeping: supervisor (4 hr/mon)	Hour	$80.00	4	16	$1,280.00
Grounds keeping (8 hr/mon): laborer	Hour	$20.00	4	32	$640.00
Admin support (8 hr/mon): clerical	Hour	$25.00	4	32	$800.00
Respiration Test(16 hr/test): technician	Hour	$55.00	4	32	$1,760.00
Soil Sampling (6 hr/event): technician	Hour	$55.00	4	32	$1,760.00
Site closeout: loader operator	Hour	$55.00		16	$880.00
Site closeout: technician	Hour	$55.00		48	$2,640.00
Site closeout: supervisor	Hour	$80.00		24	$1,920.00

O&M Labor Cost Subtotal Per Cell **$16,940.00**

Soil Sampling: 2 /cycle/cell
Soil Gas Sampling: 4 /cycle/cell
Respiration Test: 2 /cycle/cell

Total Analysis Cost **$4,830.00**

Sampling Cost Per Cell for 1 Cycle

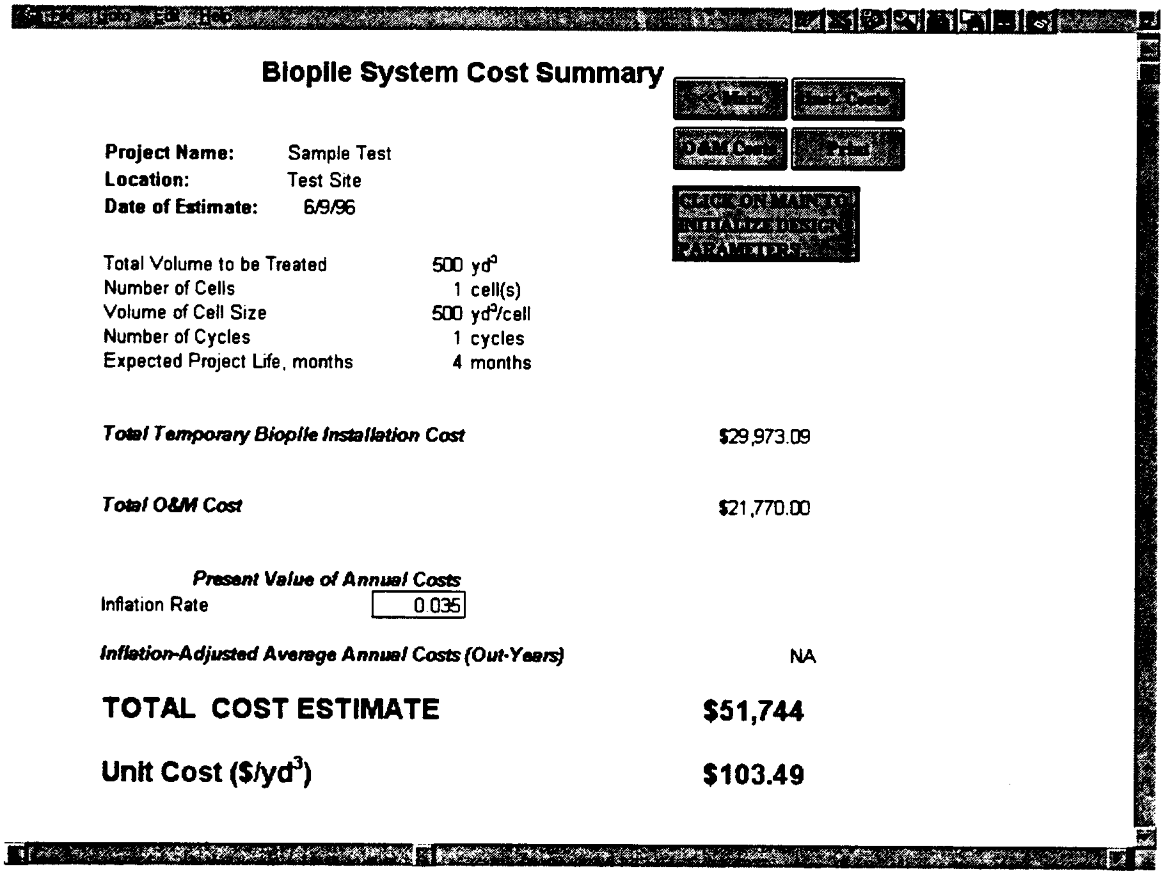
Item	Unit	Unit Cost	Quantity	Cost/Event	Cost/Cycle
Analysis soil fuel scan	event	$240.00	5	$1,200.00	$2,400.00

Cost Summary Screen

The Cost Summary Screen lists the total costs estimate for the specified design and gives the installation and O&M cost subtotals. This screen also lists the unit cost, dollars per cubic yard, of the specified design. An annual inflation factor adjusts the total cost for inflation on projects lasting more than one year.

Along with design costs, the Cost Summary Screen lists the specified design parameters and the project title, location, and date of the estimate.

Click **MAIN** to return to the main menu and **PRINT** to produce a hard copy of the Cost Summary Screen. Clicking the **INSTALLATION COST** or the **O&M COSTS** buttons will forward the program to those respective screens.



Biopile System Cost Summary

Project Name: Sample Test
Location: Test Site
Date of Estimate: 6/9/96

Total Volume to be Treated	500 yd^3
Number of Cells	1 cell(s)
Volume of Cell Size	500 yd^3/cell
Number of Cycles	1 cycles
Expected Project Life, months	4 months

Total Temporary Biopile Installation Cost	$29,973.09
Total O&M Cost	$21,770.00

Present Value of Annual Costs

Inflation Rate 0.035

Inflation-Adjusted Average Annual Costs (Out-Years)	NA
TOTAL COST ESTIMATE	**$51,744**
Unit Cost ($/$yd^3$)	**$103.49**

APPENDIX I

RESPIRATION TEST DATA CALCULATION AND WORKSHEET

The respiration test is performed to obtain data for calculating the TPH degradation rates in the biopile soil. In the respiration test, O_2 levels are measured in soil gas sampled from the monitoring points installed in various locations of the biopile. Readings generally are taken until oxygen concentrations drop below 7% or until the O_2 concentration no longer decreases. If O_2 decreases rapidly, more frequent readings will be necessary than if O_2 decreases slowly. To determine the oxygen utilization rate, oxygen percent is plotted against time. The slope of this line is referred to as the oxygen utilization rate and is reported as change of oxygen percent per day.

If low oxygen levels become a limiting factor for biodegradation, the slope of the line will level off and no longer be indicative of oxygen consumption relative to TPH degradation. In this case, only the linear portion of the curve, generally limited to data points at or above 12% O_2, will be used to calculate biodegradation rates.

The stoichiometric relationship between oxygen consumption and TPH degradation using hexane as a representative compound is shown in Equation 1:

$$C_6H_{14} + 9.5O_2 \longrightarrow 6CO_2 + 7H_2O \tag{1}$$

Using this equation, the biodegradation rate in terms of milligrams of hexane-equivalent per kilogram of soil per day can be estimated.

The first step in this calculation (Equation 2) is to convert the percentage of O_2 in soil gas to the actual amount in the form of mg O_2 / kg of soil. Properties of both oxygen and the soil consistency in the biopile are used to calculate this value. One mole of air at a temperature of 300 K would occupy a volume of 24.6 L. Assuming a soil-gas oxygen concentration such as that of ambient air (20.9%), only 5.14 L of the 24.6 L / mole soil gas would be occupied by O_2.

$$24.6\ \text{L / mole of soil gas} \times 20.9\%\ O_2 = 5.14\ \text{L of } O_2\text{ / mole of soil gas} \tag{2}$$

This value would vary according to the reported oxygen concentration. As shown in Equation 3, for example, an oxygen concentration of 15% would result in 3.69 L O_2 / mole of air instead of 5.14 L O_2 / mole of soil gas.

$$24.6\ \text{L / mole of soil gas} \times 15\%\ O_2 = 3.69\ \text{L of } O_2\text{ / mole of soil gas} \tag{3}$$

To determine the mass of the 5.14 L O_2 / mole of soil gas, the density of O_2 must be used. Because 1 mole of O_2 would have a mass of 32 g and occupy a volume of 24.6 L, the density of O_2 would be 1,300 mg / L (Equations 4 and 5).

$$32\ \text{g} \div 24.6\ \text{L of } O_2 = 1.300\ \text{g / L of } O_2 \tag{4}$$

$$1.300\ \text{g / L of } O_2 \times 1000\ \text{mg / g} = 1{,}300\ \text{mg / L of } O_2 \tag{5}$$

This value multiplied by 5.14 L / mole soil gas would yield 6,682 mg O_2 / mole soil gas (Equation 6) or 271.6 mg O_2 / L soil gas (Equation 7).

$$1{,}300\ \text{mg / L of } O_2 \times 5.14\ \text{L of } O_2\text{ / mole of soil gas} = 6{,}682\ \text{mg } O_2\text{ / mole of soil gas} \tag{6}$$

$$6{,}682\ \text{mg } O_2\text{ / mole of soil gas} \div 24.6\ \text{L / mole of soil gas} = 271.6\ \text{mg } O_2\text{ / L soil gas} \tag{7}$$

Once this relationship has been established, it must be determined what quantity of oxygen would exist in the void volume of 1 kg of soil. Assuming a soil density of 2,400 lb / yd^3 (1,424 kg / m^3), Equation 8 shows that 1 kg of soil would occupy a volume of 0.702 L.

$$(1{,}424\ \text{m}^3 / \text{kg}) \times 1{,}000\ \text{L} / \text{m}^3 = 0.702\ \text{L} / \text{kg} \tag{8}$$

Assuming a void volume of 30% in the soil, the volume of 1 kg of soil that would be occupied by soil gas is 0.21 L (Equation 9).

$$0.702\ \text{L} / \text{kg} \times 30\%\ \text{void volume} = 0.21\ \text{L soil gas} / \text{kg soil} \tag{9}$$

Using the conversion factor from Equation 7 of 271.6 mg O_2 / L air, it can be calculated in Equation 10 that 57.04 mg of O_2 would be present in 1 kg of soil at an O_2 concentration of 20.9%.

$$0.21\ \text{L soil gas} / \text{kg soil} \times 271.6\ \text{mg } O_2 / \text{L soil gas} = 57.04\ \text{mg } O_2 / \text{kg soil} \tag{10}$$

Once the change in mass of O_2 has been calculated, Equation 1 can be used to determine the mass of hydrocarbons that theoretically would be degraded. The equation yields a hydrocarbon-to-oxygen mass ratio of 1:3.5 to oxidize hexane. Therefore, if a decrease of 50 mg O_2 / kg soil were seen, then it could be assumed that 14.3 mg TPH / kg of soil had been degraded. As shown in Equation 11, the TPH degradation rate can be calculated from the O_2 degradation rate (mg O_2 / kg·h) divided by 3.5, which is the O_2-to-hydrocarbon mass ratio described above.

$$50\ \text{mg } O_2 / \text{kg} \div 3.5\ \text{mg } O_2 / \text{mg TPH} = 14.3\ \text{mg TPH} / \text{kg of soil} \tag{11}$$

Figure I-1 is a completed example of a worksheet to convert respiration sampling data (%O_2 decrease with time) to the TPH degradation rate. Figure I-2 is a blank TPH degradation worksheet that can be copied and used on site.

TPH DEGRADATION RATE WORKSHEET

1. a) O_2 concentration reading at time of blower shutdown ______ %
   b) O_2 concentration reading nearest to and greater than 12% ______ %
   c) Change in O_2 concentration (Line 1a - Line 1b) ______ %

2. a) Elapsed time from shutdown to final O_2 reading ______ hr

3. Oxygen Utilization Rate
   a) Change in O_2 concentration / elapsed time (Line 1c / Line 2a) ______ % / hr
   b) Line 3a × 24 ______ % / day

Based on the oxygen utilization rate, use the following equation to calculate degradation rate:

$$K_B = \frac{-K_O A D_O C}{100}$$

where:

K_B = degradation rate (mg / kg-day)

K_O = oxygen utilization rate (% / day)

From Line 3b ______ % / day

4. A = volume of air / kg soil (L / kg)
   a) Density of soil (if unknown assume a bulk density of 2,400 lb / yd^3) ______ lb / yd^3
   b) Vol soil / kg soil: (764.6 L / yd^3 × 2.205 lb / kg) ÷ Line 4a = ______ L / kg
   c) Vol air / kg soil: Line 4b × 0.30* = ______ L / kg
   * (assuming 30% soil porosity)

5. D_O = density of oxygen gas (mg / L)
   a) Size temperature: °C** + 273 = ______ K
   ** (assume 27°C if unknown)
   b) Volume per mole: 0.08205 × Line 5a = ______ L / mole
   c) Mass O_2 per liter: 32,000 mg / mole ÷ Line 5b ______ mg / L

6. C = mass ratio of hydrocarbon to oxygen required formineralization (1 / 3.5) ______ 0.2857

TPH Degradation Rate = (Line 3b × Line 4c × Line 5c × Line 6) ÷ 100 ______ mg / kg-day

Figure I-1. Example of a Completed TPH Degradation Rate Worksheet.

TPH DEGRADATION RATE WORKSHEET

1. a) O_2 concentration reading at time of blower shutdown ________ %
   b) O_2 concentration reading nearest to and greater than 12% ________ %
   c) Change in O_2 concentration (Line 1a - Line 1b) ________ %

2. a) Elapsed time from shutdown to final O_2 reading ________ hr

3. Oxygen Utilization Rate
   a) Change in O_2 concentration / elapsed time (Line 1c / Line 2a) ________ % / hr
   b) Line 3a × 24 ________ % / day

Based on the oxygen utilization rate, use the following equation to calculate degradation rate:

$$K_B = \frac{-K_O A D_O C}{100}$$

where:

K_B = degradation rate (mg / kg-day)

K_O = oxygen utilization rate (% / day)

From Line 3b ________ % / day

4. A = volume of air / kg soil (L / kg)
   a) Density of soil (if unknown assume a bulk density of 2,400 lb / yd^3) ________ lb / yd^3
   b) Vol soil / kg soil: (764.6 L / yd^3 × 2.205 lb / kg) ÷ Line 4a = ________ L / kg
   c) Vol air / kg soil: Line 4b × 0.30* = ________ L / kg
      * (assuming 30% soil porosity)

5. D_O = density of oxygen gas (mg / L)
   a) Size temperature: °C** + 273 = ________ K
      ** (assume 27°C if unknown)
   b) Volume per mole: 0.08205 × Line 5a = ________ L / mole
   c) Mass O_2 per liter: 32,000 mg / mole ÷ Line 5b ________ mg / L

6. C = mass ratio of hydrocarbon to oxygen required formineralization (1 / 3.5) ________ 0.2857

TPH Degradation Rate = (Line 3b × Line 4c × Line 5c × Line 6) ÷ 100 ________ mg / kg-day

Figure I-2. TPH Degradation Rate Worksheet

APPENDIX J

EXAMPLE DESIGN CALCULATIONS

J.1 Design Scenario. There are 500 yd^3 (382 m^3) of soil contaminated with 20,000 mg TPH per kg of soil to be treated. The soil has a 10% moisture content which is approximately 50% of field capacity. The soil is relatively uniform and has a minimal clay, silt, and organic content. Initial soil data show the pH to average 7.9. The total organic carbon content and N:P:K values are unknown at this point. Referring to the decision tree in Chapter 1, the biopile technology appears feasible, provided sufficient moisture and nutrients are added. Soil processing does not appear to be necessary.

J.2 Calculating the Biopile Dimensions. The following biopile dimensions are assumed:

Total soil volume to be processed = 500 yd^3 (382 m^3)
Desired biopile height = 5 to 6 ft (1.5 to 1.8 m)
Expected biopile slope at sides = 1.25:1 side to height ratio

Figure J-1 shows an example biopile.

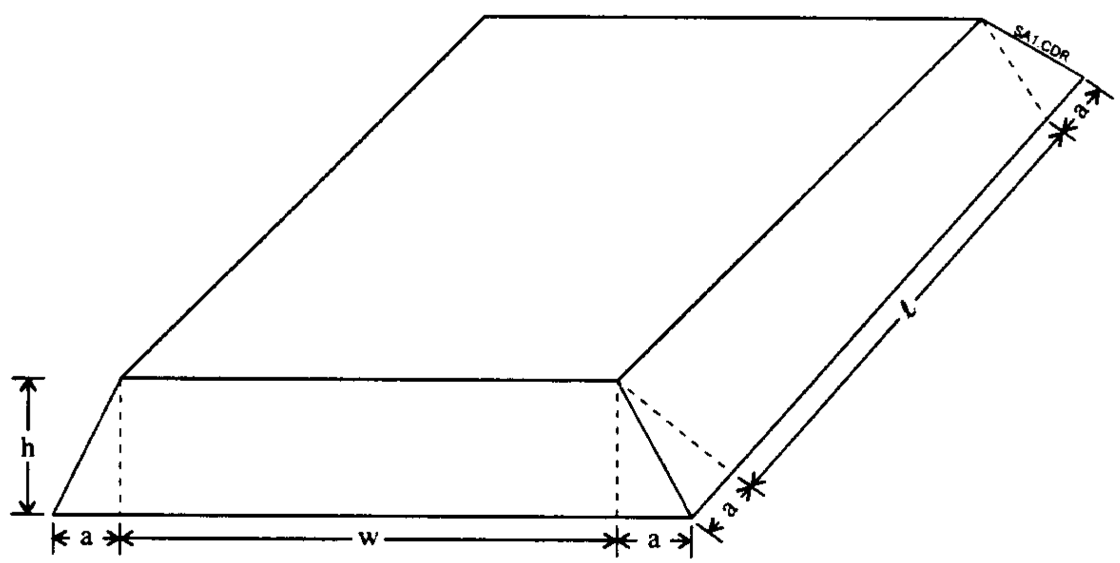


Figure J-1. Example Biopile Showing Approximate Relative Dimensions.

The pad can be sized based on the volume of soil to be processed and by assuming an average pile height and pile slope. The volume of the biopile is represented by equation (1) for the volume of a prismoid:

$$V = {}^{1}/_{6}\, h\, (B_1 + 4\, M + B_2) \qquad (1)$$

where:

V = volume of pile
h = pile height
B_1 = area of lower base
B_2 = area of upper base
M = area of biopile midsection

The design volume is 500 yd^3 = V
height is 5 ft = h

$B_1 = (l + 2a)\,(w + 2a) = lw + 2aw + 2al + 4a^2$
$B_2 = lw$
$M = (l + 2(a/2))\,(w + 2(a/2)) = lw + aw + al = a^2$
$V = (h/6)\,[(lw + 2aw + 2al + 4a^2) + lw + 4\,(lw + aw + al + a^2)]$
$V = (h/6)\,[(6\,lw = 6aw + 6al + 8a^2)]$
$V = h\,(lw + aw + al + 1.33\,a^2)$
$V/h = (l + a)w + (al + 1.33\,a^2)$
$w = [V/h - (al + 1.33\,a^2)]/(l + a)$

Solve for a:

1.25 h
h
θ
a

Assume side to height slope = 1.25:1

$\sin\theta = h/1.25\,h = 0.8$
$\theta = 53.13^{o}$
$\tan\theta = h/a = 5/a$
$a = 5/\tan(53.13) = 3.75$ ft

To size pile, choose a length and then calculate overall pile width.

Assume total pile length = 60 ft
60 ft = $l + 2a$
$l = 60 - 2a = 60 - 2\,(3.75)$
l = 52.5 ft

V = 13,500 ft^3
h = 5 ft
a = 3.75 ft
l = 52.5 ft
$w = [6{,}750\ ft^2/5\ ft - (3.75\ ft)\,(52.5\ ft) + 1.33\,(3.75\ ft)^2]/(52.5\ ft + 3.75\ ft)$
w = 44.8 ft
total pile width = 44.4 ft + 2 (3.75 ft) = 52 ft

biopile dimensions would be: 60 ft × 52 ft × 5 ft

The biopile dimensions can be calculated by selecting a new overall pad length and repeating the above calculations.

In general, the 50 ft × 60 ft pad area will be suitable for biopile designs ranging in increments of 400 to 750 yd^3. Smaller process batches may require pad resizing using the above calculation steps. Larger volumes of soil can be processed using multiple 500-yd^3 pads. Generally the minimum pile height should be 3½ ft and the maximum pile height should be 8 ft.

J.3 Calculating the Amount of Nutrients to Be Added

J.3 Calculating the Amount of Nutrients to Be Added. Figure J-2 is a completed example of a worksheet to complete the nutrient calculations presented below. Figure J-3 is a blank biopile nutrient addition worksheet that can be copied and used on site.

Soil contamination level = 20,000 / mg / kg

Total organic content unknown:

Assume C-content = 20,000 mg / kg (0.8) = 16,000 mg / kg
Desired C:N:P = 100:15:1
N needed = (16,000 mg / kg) × (15 / 100) = 2,400 mg / kg
P needed = (16,000 mg / kg) × (1 / 100) = 160 mg / kg

Total kg soil:

Assume soil density = 2,400 lb / yd^3
Soil volume = 500 yd^3 = 382 m^3
Total soil mass (lb) = 500 yd^3 (2,400 lb / yd^3) = 1,200,000 lb
Total soil mass (kg) = 1,200,000 lb (0.45359 kg / lb) = 544,308 kg

Total P-source needed:

P needed = (544,308 kg soil) (160 mg P / kg soil) (1 kg / 1,000,000 mg)
= 87.1 kg P
= (87.1 kg N) (2.2046 lb / kg) = **192 lb**

P-source = diammonium phosphate, $(NH_3)_2HPO_4$

Note: Diammonium phosphate (DAP) contains nitrogen as well as phosphorous. The nitrogen in this nutrient source should be counted as part of the total N supplied.

lb P / lb DAP HPO_4 = 0.24
DAP needed = (192 lb P) ÷ (0.24 lb P / lb DAP)
= **800 lb DAP**

Total N-source needed:

N needed = (544,308 kg soil) (2,400 mg N / kg soil) (l kg / 1,000,000 mg)
= 1,306 kg N
= (1,306 kg) (2.2046 lb / kg) = **2,880 lb N**

BIOPILE NUTRIENT ADDITION WORKSHEET

1. Nutrient Source:
   a. Nitrogen source (e.g. urea) ________ ________ weight fraction nitrogen (urea = 0.46)(a)
   b. Phosphorus source (e.g. diammonium phosphate) ________ ________ weight fraction phosphorus
   c. Potassium source (e.g. potassium sulfate) ________ ________ weight fraction potassium

2. Total organic carbon content in soil: ________ mg / kg dry soil. Obtained from laboratory results. If unknown, calculate as below:
   a. Average concentration of hydrocarbon contamination in soil = ________ mg / kg dry soil
   b. Average carbon content in contamination = line 2a × 0.8 = ________ mg carbon / kg dry soil

3. Desired C:N:P:K ratio. Determine by treatability tests, else use C:N:P:K = 100:15:1:1.

4. Amount of nutrient to add per kg of dry soil. (If not known, assume negligible N,P,K content in soil prior to nutrient addition.)
   a. Nitrogen (N) needed to be added per kg dry soil = line 2b. × 0.15 = ________ mg N / kg soil
   b. Phosphorus (P) needed to be added per kg dry soil = line 2b. × 0.01 = ________ mg P / kg soil
   c. Potassium (K) needed to be added per kg dry soil = line 2b. × 0.01 = ________ mg K / kg soil

5. Bulk density of soil = ________ kg / m^3.[b] (Assume 1,400 kg / m^3 if unknown.)

6. Nutrients required per m^3 of soil:
   a. kg N / m^3 soil = line 4a. × line 5 ÷ 1,000,000 = ________ kg N / m^3 soil
   b. kg P / m^3 soil = line 4b. × line 5 ÷ 1,000,000 = ________ kg P / m^3 soil
   c. kg K / m^3 soil = line 4c. × line 5 ÷ 1,000,000 = ________ kg K / m^3 soil

7. Pounds of nutrients required per cubic yards of soil
   a. lb N / yd^3 soil = line 6a. × 1.69 = ________ lb N / yd^3 soil
   b. lb P / yd^3 soil = line 6b. × 1.69 = ________ lb P / yd^3 soil
   c. lb K / yd^3 soil = line 6c. × 1.69 = ________ lb K / yd^3 soil

8. Total volume of soil to be treated by biopile: ________ yd^3

9. Pounds of nutrient source to be added per cubic yard of soil:
   line 7a. ÷ line 1a. = ________ lb of N source required / yd^3 soil
   line 7b. ÷ line 1b. = ________ lb of P source required / yd^3 soil
   line 7c. ÷ line 1c. = ________ lb of K source required / yd^3 soil

10. Total pounds of nutrient sources required for the biopile:
    line 9a. × line 8 = ________ lb of N source(c) to be purchased
    line 9b. × line 8 = ________ lb of P source to be purchased
    line 9c. × line 8 = ________ lb of K source to be purchased

(a) Weight fraction = % ÷ 100.
(b) 1 kg / m^3 = 1.688 lb / yd^3.
(c) Assumes all N comes from a single source. In this example calculation, it is urea.
NA = not applicable.

Figure J-2. Example of a Completed Biopile Nutrient Addition Worksheet.

BIOPILE NUTRIENT ADDITION WORKSHEET

1. Nutrient Source:
   a. Nitrogen source (e.g. urea) ________ ________ weight fraction nitrogen (urea = 0.46)(a)
   b. Phosphorus source (e.g. diammonium phosphate) ________ ________ weight fraction phosphorus
   c. Potassium source (e.g. potassium sulfate) ________ ________ weight fraction potassium

2. Total organic carbon content in soil: ________ mg / kg dry soil. Obtained from laboratory results. If unknown, calculate as below:
   a. Average concentration of hydrocarbon contamination in soil = ________ mg / kg dry soil
   b. Average carbon content in contamination = line 2a × 0.8 = ________ mg carbon / kg dry soil

3. Desired C:N:P:K ratio. Determine by treatability tests, else use C:N:P:K = 100:15:1:1.

4. Amount of nutrient to add per kg of dry soil. (If not known, assume negligible N,P,K content in soil prior to nutrient addition.)
   a. Nitrogen (N) needed to be added per kg dry soil = line 2b. × 0.15 = ________ mg N / kg soil
   b. Phosphorus (P) needed to be added per kg dry soil = line 2b. × 0.01 = ________ mg P / kg soil
   c. Potassium (K) needed to be added per kg dry soil = line 2b. × 0.01 = ________ mg K / kg soil

5. Bulk density of soil = ________ kg / m^3.[b] (Assume 1,400 kg / m^3 if unknown.)

6. Nutrients required per m^3 of soil:
   a. kg N / m^3 soil = line 4a. × line 5 ÷ 1,000,000 = ________ kg N / m^3 soil
   b. kg P / m^3 soil = line 4b. × line 5 ÷ 1,000,000 = ________ kg P / m^3 soil
   c. kg K / m^3 soil = line 4c. × line 5 ÷ 1,000,000 = ________ kg K / m^3 soil

7. Pounds of nutrients required per cubic yards of soil
   a. lb N / yd^3 soil = line 6a. × 1.69 = ________ lb N / yd^3 soil
   b. lb P / yd^3 soil = line 6b. × 1.69 = ________ lb P / yd^3 soil
   c. lb K / yd^3 soil = line 6c. × 1.69 = ________ lb K / yd^3 soil

8. Total volume of soil to be treated by biopile: ________ yd^3

9. Pounds of nutrient source to be added per cubic yard of soil:
   line 7a. ÷ line 1a. = ________ lb of N source required / yd^3 soil
   line 7b. ÷ line 1b. = ________ lb of P source required / yd^3 soil
   line 7c. ÷ line 1c. = ________ lb of K source required / yd^3 soil

10. Total pounds of nutrient sources required for the biopile:
    line 9a. × line 8 = ________ lb of N source(c) to be purchased
    line 9b. × line 8 = ________ lb of P source to be purchased
    line 9c. × line 8 = ________ lb of K source to be purchased

(a) Weight fraction = % ÷ 100.
(b) 1 kg / m^3 = 1.688 lb / yd^3.
(c) Assumes all N comes from a single source.
NA = not applicable.

Figure J-3. Biopile Nutrient Addition Worksheet.

lb N-source needed:

First calculate amount of N supplied by DAP
$(NH_3)_2HPO_4$ is 21.5% N = 0.22 lb N/lb DAP

N supplied by DAP = (800 lb DAP) × 0.22 lb N/1 lb DAP)
= 176 lb N from DAP

Primary N-source = urea
1 lb N/lb urea = 0.46

Urea needed = (2,880 lb N - 176 lb N from DAP) ÷ (0.46 lb N/lb urea)
= **5,880 lb urea**

Nutrients to purchase: 5,880 lb urea; 800 lb diammonium phosphate

K-source needed:

Addition of potassium (K) usually is not required. Where treatability studies indicate insufficient K, the K can be added in half the amount of P. Potash (K_2CO_3) is a common K-source.

J.4 Calculating the Nutrient Application Rate. To ensure even nutrient distribution, N- and P-sources should be applied uniformly throughout the soil. Therefore, the nutrient application rate (lb of each nutrient added per unit mass or volume of soil) should be calculated.

From earlier calculations, it is known that 2,400 mg N/kg soil and 160 mg P/kg soil will be needed.

Amount DAP required/kg soil = (160 mg P/kg soil) (1 mg DAP/0.24 mg P) = 667 mg DAP/kg soil
= **0.667 kg DAP/1,000 kg soil**

Amount urea required/kg soil = (2,400 - 0.22(667)) (1/0.46) = 4,898 mg urea/kg soil
= **4.90 kg urea/1,000 kg soil**

Assuming a soil density of 1,420 kg/m^3, the amount of nutrients needed per unit volume can be calculated:
(0.667 kg DAP/1,000 kg soil) (1,420 kg/m^3) = **0.95 kg DAP/m^3 soil**

(4.90 kg urea/1,000 kg soil) (1,420 kg/m^3) = **6.96 kg urea/m^3 soil**

Converting kg/m^3 to lb/yd^3:
(0.95 kg DAP/m^3 soil) (2.205 lb/kg) (0.765 m^3/yd^3) = **1.6 lb DAP/yd^3 soil**
(6.96 kg urea/m^3 soil) (2.205 lb/kg) (0.765 m^3/yd^3) = **11.7 lb urea/yd^3 soil**

J.5 Calculating the Initial Moisture Addition Requirement. From the design scenario, the soil contains 10% H_2O and is at 50% of field capacity. The target field capacity will be 95%.

% moisture at which soil will be at 95% field capacity:
Make the simplifying assumption that there is a linear relationship between moisture content and field capacity.

$$50\% \text{ field capacity} / 10\% \text{ moisture} = 95\% \text{ field capacity} \div x\% \text{ moisture}$$

$$x\% \text{ moisture} = (95\%)(10\%) \div 50\% = 19\%$$

Therefore, enough water must be added to the soil to bring the moisture content to 19%.

Amount of water to be added per kg of soil:

Prior to moisture addition, 1 kg soil contains 0.1 kg H_2O.
After moisture addition, 1 kg soil should contain 0.19 kg H_2O.

In 1 kg of soil at 19% moisture, 0.81 kg would be dry soil. The soil on hand contains 10% moisture.

At 10% moisture, the total mass of soil containing 0.81 kg dry soil would be (0.81 / 0.9) = 0.9 kg.

The 0.9 kg of 10% H_2O soil would therefore contain 0.81 kg dry soil; and 0.09 kg H_2O.

To get to 1 kg of soil at 19% moisture, 0.1 kg H_2O must be added to every 0.9 kg of 10% H_2O soil, which equals:

0.1 kg H_2O / 0.9 kg of 10% H_2O soil = 0.111 kg H_2O / kg 10% soil
soil density = 2,400 lb / yd^3 (1 kg / 2.204 lb)
= 1,089 kg / yd^3

Volume H_2O to add per yd^3 of soil = (0.111 kg H_2O / kg 10% H_2O) (1,089 kg / yd^3)
(1 L kg / kg H_2O) (1 gal / 3.79 L) = 32 gal / yd^3