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How To Evaluate Alternative Cleanup Technologies For Underground Storage Tank Sites

A Guide For Corrective Action Plan Reviewers

Chapter IV

Biopiles

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Chapter IV
Biopiles

Overview

Biopiles, also known as biocells, bioheaps, biomounds, and compost piles, are used to reduce concentrations of petroleum constituents in excavated soils through the use of biodegradation. This technology involves heaping contaminated soils into piles (or “cells”) and stimulating aerobic microbial activity within the soils through the aeration and/or addition of minerals, nutrients, and moisture. The enhanced microbial activity results in degradation of adsorbed petroleum-product constituents through microbial respiration. Biopiles are similar to landfarms in that they are both above-ground, engineered systems that use oxygen, generally from air, to stimulate the growth and reproduction of aerobic bacteria which, in turn, degrade the petroleum constituents adsorbed to soil. While landfarms are aerated by tilling or plowing, biopiles are aerated most often by forcing air to move by injection or extraction through slotted or perforated piping placed throughout the pile. (Chapter V provides a detailed description of landfarming.) A typical biopile cell is shown in Exhibit IV-1.

Biopiles, like landfarms, have been proven effective in reducing concentrations of nearly all the constituents of petroleum products typically found at underground storage tank (UST) sites. Lighter (more volatile) petroleum products (e.g., gasoline) tend to be removed by evaporation during aeration processes (i.e., air injection, air extraction, or pile turning) and, to a lesser extent, degraded by microbial respiration. Depending upon your state's regulations for air emissions of volatile organic compounds (VOCs), you may need to control the VOC emissions. Control involves capturing the vapors before they are emitted to the atmosphere, passing them through an appropriate treatment process, and then venting them to the atmosphere. The mid-range hydrocarbon products (e.g., diesel fuel, kerosene) contain lower percentages of lighter (more volatile) constituents than does gasoline. Biodegradation of these petroleum products is more significant than evaporation. Heavier (non-volatile) petroleum products (e.g., heating oil, lubricating oils) do not evaporate during biopile aeration; the dominant mechanism that breaks down these petroleum products is biodegradation. However, higher molecular weight petroleum constituents such as those found in heating and lubricating oils, and, to a lesser extent, in diesel fuel and kerosene, require a longer period of time to degrade than do the constituents in gasoline. A summary of the advantages and disadvantages of biopiles is shown in Exhibit IV-2.

Exhibit IV-1
Typical Biopile System

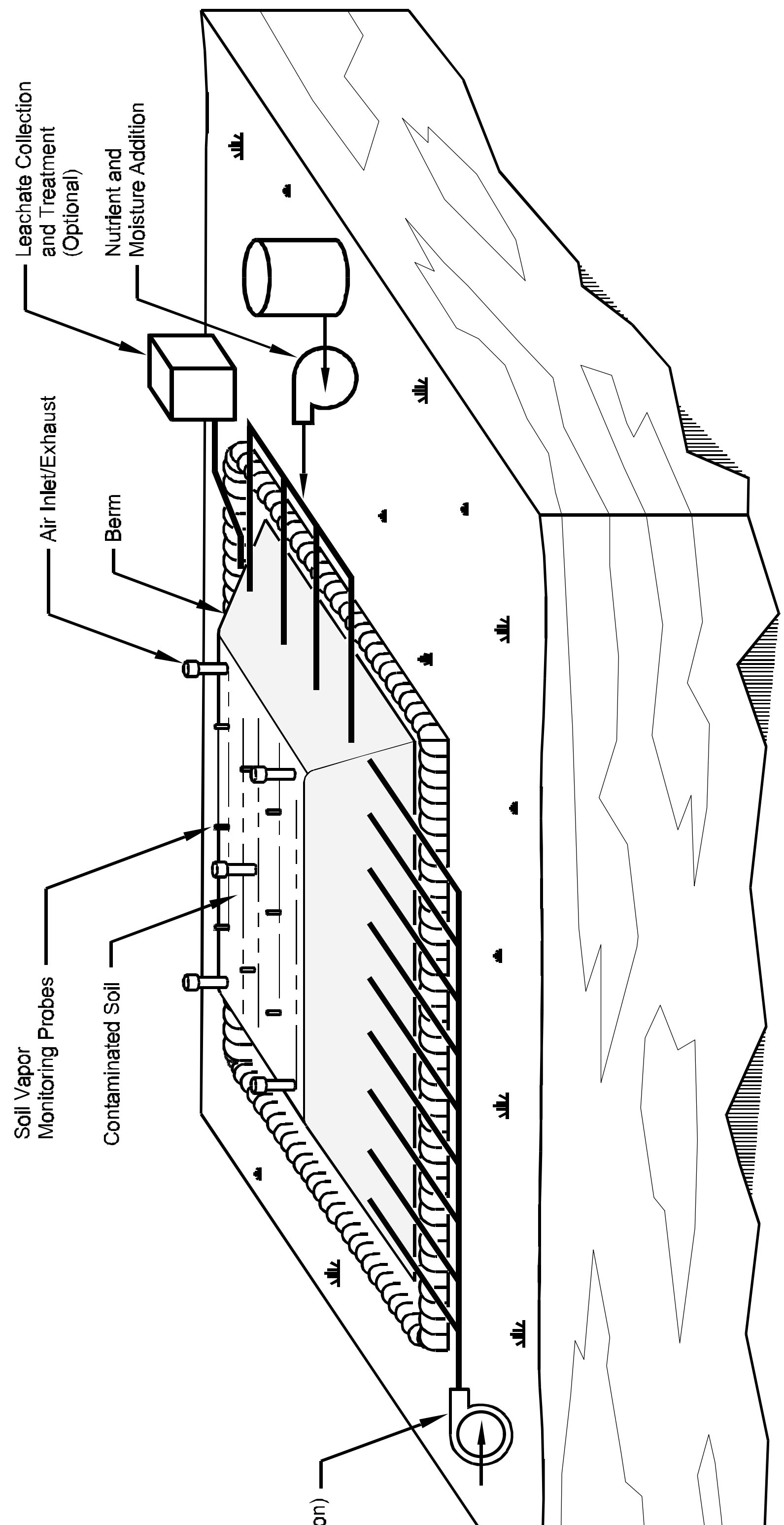


Exhibit IV-2
Advantages And Disadvantages Of Biopiles

Advantages	Disadvantages
❍ Relatively simple to design and implement.	❍ Concentration reductions > 95% and constituent concentrations < 0.1 ppm are very difficult to achieve.
❍ Short treatment times: usually 6 months to 2 years under optimal conditions.	❍ May not be effective for high constituent concentrations (> 50,000 ppm total petroleum hydrocarbons).
❍ Cost competitive: $30-90/ton of contaminated soil.	❍ Presence of significant heavy metal concentrations (> 2,500 ppm) may inhibit microbial growth.
❍ Effective on organic constituents with slow biodegradation rates.	❍ Volatile constituents tend to evaporate rather than biodegrade during treatment.
❍ Requires less land area than landfarms.	❍ Requires a large land area for treatment, although less than landfarming.
❍ Can be designed to be a closed system; vapor emissions can be controlled.	❍ Vapor generation during aeration may require treatment prior to discharge.
❍ Can be engineered to be potentially effective for any combination of site conditions and petroleum products.	❍ May require bottom liner if leaching from the biopile is a concern.

This chapter will assist you in evaluating a corrective action plan (CAP) that proposes biopiles as a remedy for petroleum-contaminated soil. The evaluation guidance is presented in the three steps described below. The evaluation process, summarized in a flow diagram shown in Exhibit IV-3, will serve as a roadmap for the decisions you will make during your evaluation. A checklist has been provided at the end of this chapter for you to use as a tool for evaluating the completeness of the CAP and for focusing on areas where additional information may be needed. Because a biopile system can be engineered to be potentially effective for any combination of site conditions and petroleum products, the evaluation process for this technology does not include initial screening. The evaluation process can be divided into the following steps.

❍ **Step 1: *An evaluation of biopile effectiveness***, in which you can identify the soil, constituent, and climatic factors that contribute to the effectiveness of biopiles and compare them to acceptable operating ranges. To complete the evaluation, you will need to compare these properties to ranges in which biopiles are effective.

Exhibit IV-3
Biopile Evaluation Process Flow Chart

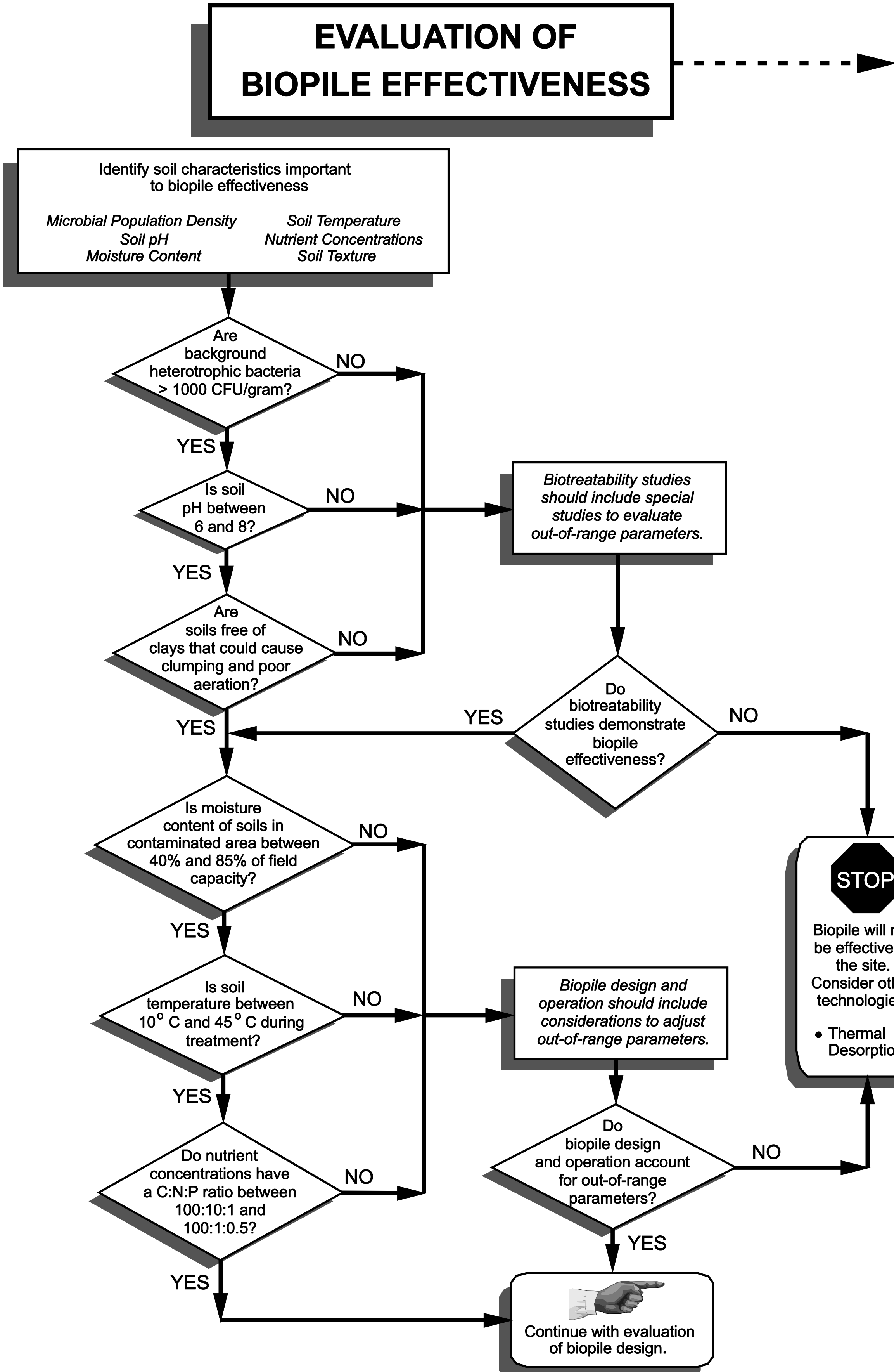


Exhibit IV-3
Biopile Evaluation Process Flow Chart

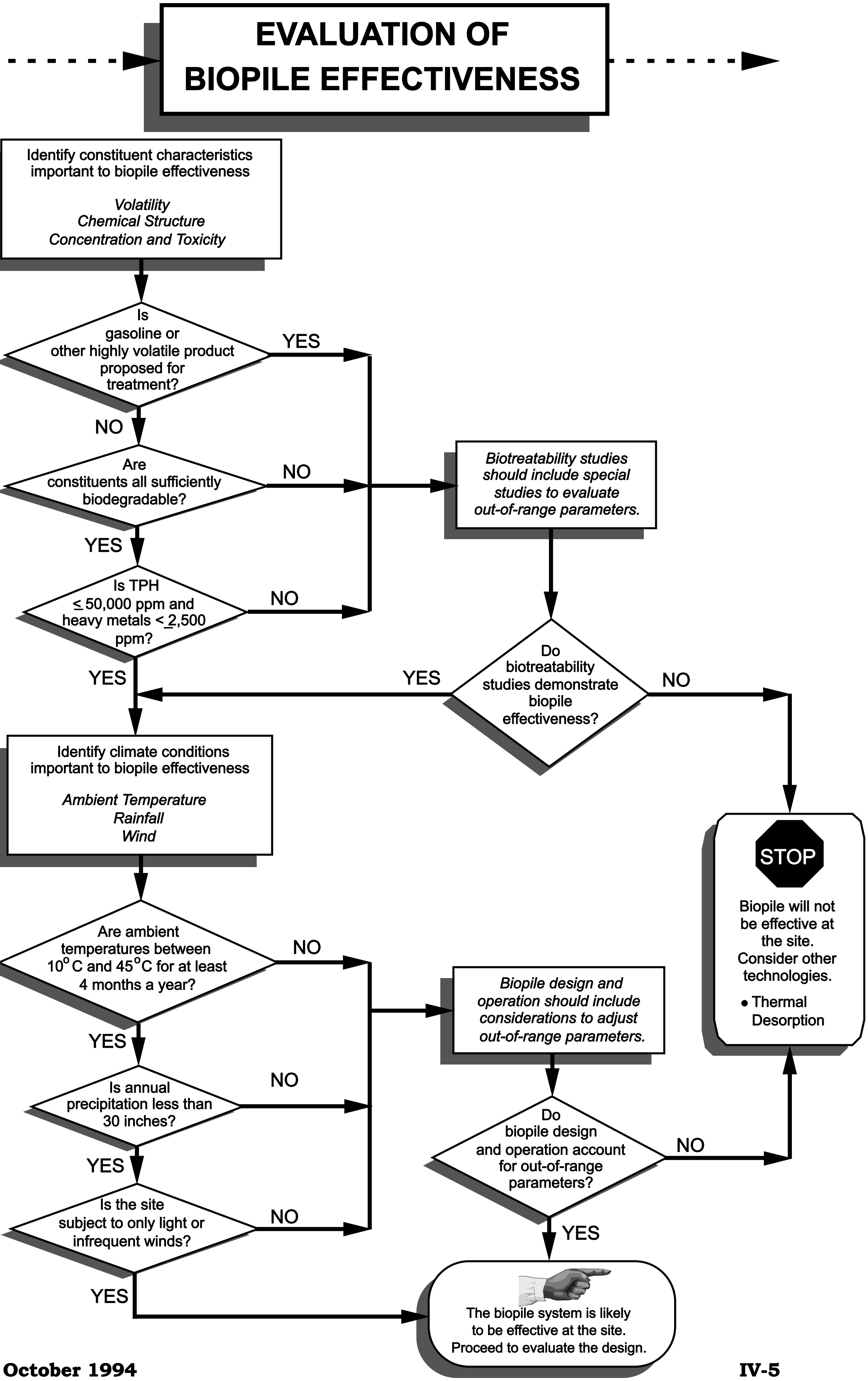
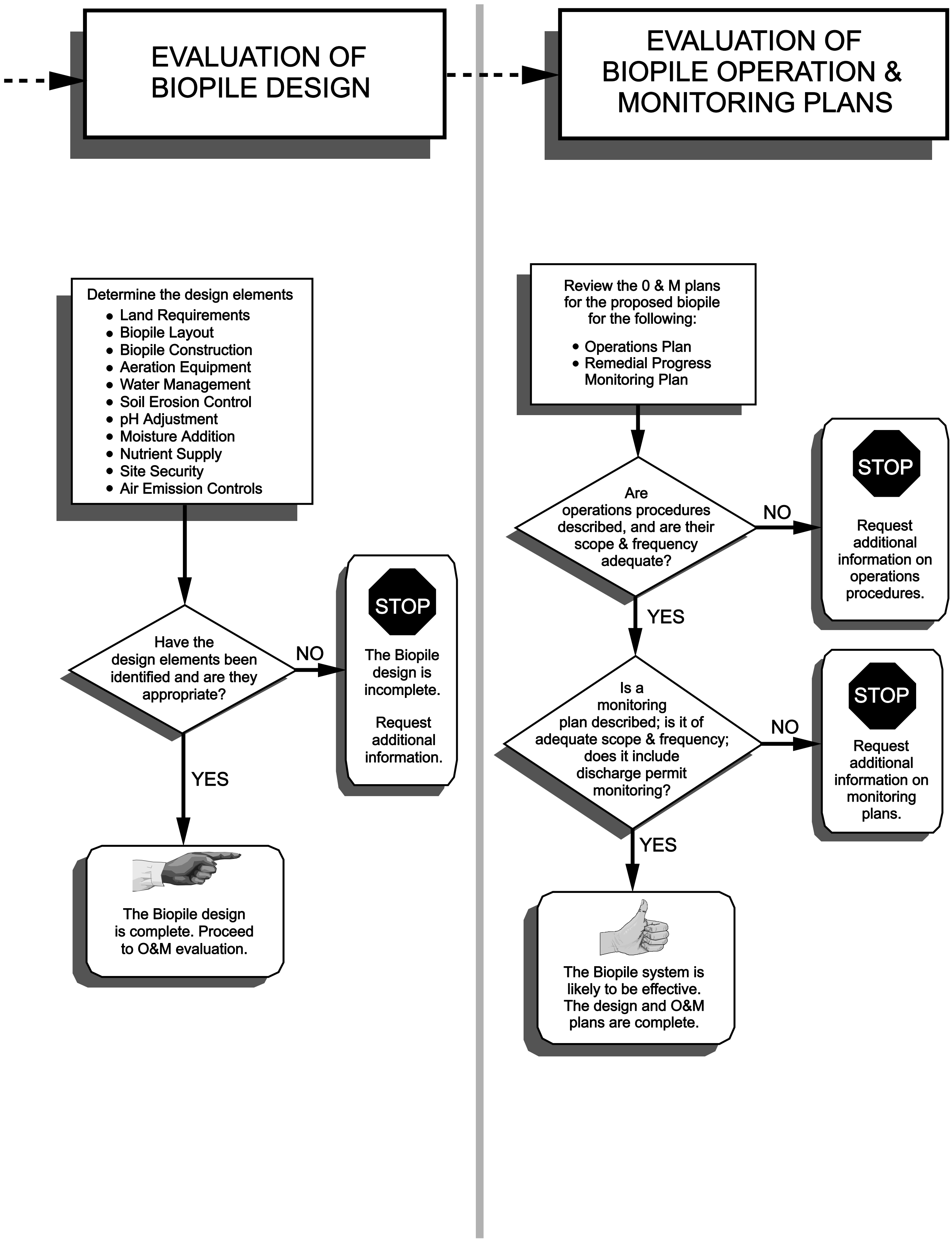


Exhibit IV-3
Biopile Evaluation Process Flow Chart



- **Step 2: An *evaluation of the biopile system design*** will allow you to determine if the rationale for the design has been appropriately defined, whether the necessary design components have been specified, and whether the construction designs are consistent with standard practice.

- **Step 3: An *evaluation of the operation and monitoring plans,*** which are critical to the effectiveness of biopiles, will allow you to determine whether start-up and long-term system operation and monitoring plans are of sufficient scope.

Evaluation Of Biopile Effectiveness

The effectiveness of a biopile system depends on many parameters which are listed in Exhibit IV-4. The parameters are grouped into three categories: soil characteristics, constituent characteristics, and climatic conditions.

Exhibit IV-4
Parameters Used To Evaluate The Effectiveness Of Biopile Systems

Soil Characteristics	Constituent Characteristics	Climatic Conditions
Microbial population density	Volatility	Ambient temperature
Soil pH	Chemical structure	Rainfall
Moisture content	Concentration and toxicity	Wind
Soil temperature		
Nutrient concentrations		
Soil texture		

The following paragraphs contain descriptions of each parameter that include: why it is important; how it can be determined; and what its appropriate range is. During your evaluation, remember that because a biopile is an above-ground treatment technique, most parameters (except climatic conditions) can be controlled during the design and operation of the biopile. Therefore, during your evaluation, identify those parameters that fall outside the effective ranges provided and verify that the system design and proposed operating specifications compensate for any site conditions that are less than optimal.

Soil Characteristics

Microbial Population Density

Soil normally contains large numbers of diverse microorganisms including bacteria, algae, fungi, protozoa, and actinomycetes. In well-drained soils, which are most appropriate for biopiles, these organisms are generally aerobic. Of these organisms, bacteria are the most numerous and biochemically active group, particularly at low oxygen levels. Bacteria require a carbon source for cell growth and an energy source to sustain metabolic functions required for growth. Bacteria also require nitrogen and phosphorus for cell growth. Although sufficient types and quantities of microorganisms are usually present in the soil for landfarming, recent applications of ex-situ soil treatment include blending the soil with cultured microorganisms or animal manure (typically from chickens or cows). Incorporating manure serves to both augment the microbial population and provide additional nutrients. Recently, the use of a certain fungi for biodegradation of organic contaminants has been proposed based on promising laboratory tests. Microorganisms require inorganic nutrients such as nitrogen and phosphorus to support cell growth and sustain biodegradation processes. Nutrients may be available in sufficient quantities in the site soils but, more frequently, nutrients need to be added to the biopile soils to maintain bacterial populations.

The metabolic process used by bacteria to produce energy requires a terminal electron acceptor (TEA) to enzymatically oxidize the carbon source to carbon dioxide. Microbes are classified by the carbon and TEA sources they use to carry out metabolic processes. Bacteria that use organic compounds (e.g., petroleum constituents and other naturally occurring organics) as their source of carbon are *heterotrophic;* those that use inorganic carbon compounds (e.g., carbon dioxide) are *autotrophic.* Bacteria that use oxygen as their TEA are *aerobic;* those that use a compound other than oxygen, (e.g., nitrate, sulfate), are *anaerobic;* and those that can utilize both oxygen and other compounds as TEAs are *facultative.* For applications directed at cleaning up petroleum products, only bacteria that are both *aerobic* (or *facultative*) and *heterotrophic* are important in the degradation process.

In order to evaluate the presence and population of naturally occurring bacteria that will contribute to degradation of petroleum constituents, conduct laboratory analyses of soil samples from the site. These analyses, at a minimum, should include plate counts for total heterotrophic bacteria. Plate count results are normally reported in terms of colony-forming units (CFUs) per gram of soil. Microbial population densities in typical soils range from 10^4 to 10^7 CFU/gram of soil. For biopiles to be effective the minimum heterotrophic plate count should be 10^3 CFU/gram or greater. Plate counts lower than 10^3 could indicate the presence of toxic concentrations of organic or inorganic (e.g., metals) compounds. In this situation, biopiles may still be effective if the soil is conditioned or amended to reduce the toxic concentrations and increase the microbial population density. More elaborate laboratory tests are sometimes conducted to identify the bacterial species present. This may be desirable if there is uncertainty about whether microbes capable of degrading specific petroleum hydrocarbons occur naturally in the soil. If insufficient numbers or types of microorganisms are present, the population density may be increased by introducing cultured microbes that are available from numerous different vendors. See Exhibit IV-5 for the relationship between counts of total heterotrophic bacteria and the effectiveness of biopiles.

Exhibit IV-5
Heterotrophic Bacteria And Biopile Effectiveness

Total Heterotrophic Bacteria (prior to biopile operation)	Biopile Effectiveness
> 1,000 CFU/gram dry soil	Generally effective.
< 1,000 CFU/gram dry soil	May be effective; needs further evaluation to determine if toxic conditions are present.

The use of fungi (specifically the white rot fungus) is emerging as a remedial technology that may be effective on many types of organic contaminants. These fungi do not metabolize contaminants; degradation occurs outside their cells. The fungi degrade lignin, which must be supplied to them, usually in the form of sawdust or woodchips blended with the soil. In the process of degrading lignin, the fungi excrete other chemicals that degrade the organic contaminants. This process is called co-metabolism. Although the technology has not as yet been subject to extensive field testing, laboratory tests show it can degrade organic chemicals to non-detectable levels.

Soil pH

To support bacterial growth, the soil pH should be within the 6 to 8 range, with a value of about 7 (neutral) being optimal. Soils with pH values outside this range prior to biopile operation will require pH adjustment during construction of the biopile and during operation of the biopile. Soil pH within the biopile soils can be raised through the addition of lime and lowered by adding elemental sulfur during construction. Liquid solutions may also be injected into the biopile during operations to adjust pH. However, mixing with soils during construction results in more uniform distribution. Exhibit IV-6 summarizes the effect of soil pH on biopile effectiveness. Review the CAP to verify that soil pH measurements have been made. If the soil pH is less than 6 or greater than 8, make sure that pH adjustments, in the form of soil amendments, are included in the construction plans for the biopile and that the operations plan includes monitoring of pH.

Exhibit IV-6
Soil pH And Biopile Effectiveness

Soil pH (prior to biopile construction)	Biopile Effectiveness
$6 \leq pH \leq 8$	Generally effective.
$6 > pH > 8$	Biopile soils will require amendments to correct pH to effective range.

Moisture Content

Soil microorganisms require moist soil conditions for proper growth. Excessive soil moisture, however, restricts the movement of air through the subsurface thereby reducing the availability of oxygen which is essential for aerobic bacterial metabolic processes. In general, soils should be moist but not wet or dripping wet. The ideal range for soil moisture is between 40 and 85 percent of the water-holding capacity (field capacity) of the soil or about 12 percent to 30 percent by weight. Periodically, moisture must be added to the biopile because soils become dry as a result of evaporation, which is increased during aeration operations. Excessive accumulation of moisture can occur within biopiles in areas with high precipitation or poor drainage. These conditions should be considered in the biopile design. For example, an impermeable cover can mitigate excess infiltration and potential erosion of the biopile. Exhibit IV-7 shows the optimal range for soil moisture content.

Exhibit IV-7
Soil Moisture And Biopile Effectiveness

Soil Moisture	Biopile Effectiveness
40% ≤ field capacity ≤ 85%	Effective.
Field capacity < 40%	Periodic moisture addition is needed to maintain proper bacterial growth.
Field capacity > 85%	Biopile design should include special water drainage considerations or impervious cover.

Soil Temperature

Bacterial growth rate is a function of temperature. Soil microbial activity has been shown to significantly decrease at temperatures below 10°C and to essentially cease below 5°C. The microbial activity of most bacteria important to petroleum hydrocarbon biodegradation also diminishes at temperatures greater than 45°C. Within the range of 10°C to 45°C, the rate of microbial activity typically doubles for every 10°C rise in temperature. Because soil temperature varies with ambient temperature, there will be certain periods during the year when bacterial growth and, therefore, constituent degradation will diminish. When ambient temperatures return to the growth range, bacterial activity will be gradually restored.

In colder parts of the United States, such as the Northeastern states, optimum operating temperatures typically exist for periods of 7 to 9 months. In very cold climates, special precautions can be taken, including enclosing the biopile within a greenhouse-type structure, injecting heated air into the biopile, or introducing special bacteria capable of activity at lower temperatures. In warm regions, optimum temperatures for biopile effectiveness can last all year. Exhibit IV-8 shows how soil temperature affects biopile operation.

Exhibit IV-8
Soil Temperature And Biopile Effectiveness

Soil Temperature	Biopile Effectiveness
10°C ≤ soil temperature ≤ 45°C	Effective.
10°C > soil temperature > 45°C	Not generally effective; microbial activity diminished during seasonal temperature extremes but restored during periods within the effective temperature range. Temperature-controlled enclosures, heated (or cooled) air injection, or special bacteria required for areas with extreme temperatures.

Nutrient Concentrations

Microorganisms require inorganic nutrients such as nitrogen and phosphorus to support cell growth and sustain biodegradation processes. Nutrients may be available in sufficient quantities in the site soils but, more frequently, nutrients need to be added to the biopile soils to maintain bacterial populations. However, excessive amounts of certain nutrients (i.e., phosphate and sulfate) can repress microbial metabolism. The typical carbon:nitrogen:phosphorus ratio necessary for biodegradation falls in the range of 100:10:1 to 100:1:0.5, depending on the specific constituents and microorganisms involved in the biodegradation process.

The naturally occurring available nitrogen and phosphorus content of the soil should be determined by chemical analyses of samples collected from the site. These types of analyses are routinely conducted in agronomic laboratories that test soil fertility for farmers. These concentrations can be compared to the nitrogen and phosphorus requirements calculated from the stoichiometric ratios of the biodegradation process. A conservative approximation of the amount of nitrogen and phosphorus required for optimum degradation of petroleum products can be calculated by assuming that the total mass of hydrocarbon in the soil represents the mass of carbon available for biodegradation. This simplifying assumption is valid because the carbon content of the petroleum hydrocarbons commonly encountered at UST sites is approximately 90 percent carbon by weight.

As an example, assume that at a LUST site the volume of contaminated soil is 90,000 ft^3, the average TPH concentration in the contaminated soil is 1,000 mg/kg, and the soil bulk density is 50 kg/ft^3 (1.75 g/cm^3).

The mass of contaminated soil is equal to the product of volume and bulk density:

$$\text{soil mass} = 90{,}000\ \text{ft}^3 \times \frac{50\ \text{kg}}{\text{ft}^3} = 4.5 \times 10^6\ \text{kg}$$

The mass of the contaminant (and carbon) is equal to the product of the mass of contaminated soil and the average TPH concentration in the contaminated soil:

$$\text{contaminant mass} = 4.5 \times 10^6\ \text{kg} \times 1{,}000\ \frac{\text{mg}}{\text{kg}} = 4.5 \times 10^3\ \text{kg} \approx 10{,}000\ \text{lbs}$$

Using the C:N:P ratio of 100:10:1, the required mass of nitrogen would be 1,000 lbs, and the required mass of phosphorus would be 100 lbs. After converting these masses into concentration units (56 mg/kg for nitrogen and 5.6 mg/kg for phosphorus), they can be compared with the results of the soil analyses to determine if nutrient addition is necessary. If nitrogen addition is necessary, slow release sources should be used. Nitrogen additions can lower soil pH, depending on the amount and type of nitrogen added.

Soil Texture

Texture affects the permeability, moisture content, and bulk density of the soil. To ensure that oxygen addition (by air extraction or injection), nutrient distribution, and moisture content of the soils can be maintained within effective ranges, you must consider the texture of the soils. For example, soils that tend to clump together (such as clays) are difficult to aerate and result in low oxygen concentrations. It is also difficult to uniformly distribute nutrients throughout these soils. They also retain water for extended periods following a precipitation event.

You should identify whether clayey soils are proposed for the biopile at the site. Soil amendments (e.g., gypsum) and bulking materials (e.g., sawdust, or straw) should be blended into the soil as the biopile is being constructed to ensure that the biopile medium has a loose or divided texture. Clumpy soil may require shredding or other means of pretreatment during biopile construction to incorporate these amendments.

Constituent Characteristics

Volatility

The volatility of contaminants proposed for treatment in biopiles is important because volatile constituents tend to evaporate from the biopile into the air during extraction or injection, rather than being biodegraded by bacteria. Constituent vapors in air that is injected into the biopile will dissipate into the atmosphere unless the biopile is covered and collection piping is installed beneath the cover. If air is added to the pile by applying a vacuum to the aeration piping, volatile constituent vapors will pass into the extracted air stream which can be treated, if necessary. In some cases (where allowed), it may be acceptable to reinject the extracted vapors back into the soil pile for additional degradation. It is important to optimize the aeration rate to the biopile. Evaporation of volatile constituents can be reduced by minimizing the air extraction or injection rate, which also reduces degradation rates by reducing oxygen supply to bacteria.

Petroleum products generally encountered at UST sites range from those with a significant volatile fraction, such as gasoline, to those that are primarily nonvolatile, such as heating and lubricating oils. Petroleum products generally contain more than one hundred different constituents that possess a wide range of volatility. In general, gasoline, kerosene, and diesel fuels contain constituents with sufficient volatility to evaporate from a biopile. Depending upon state-specific regulations for air emissions of volatile organic compounds (VOCs), control of VOC emissions may be required. Control involves capturing vapors before they are emitted to the atmosphere and then passing them through an appropriate treatment process before being vented to the atmosphere.

Chemical Structure

The chemical structures of the contaminants present in the soils proposed for treatment by biopiles are important in determining the rate at which biodegradation will occur. Although nearly all constituents in petroleum products typically found at UST sites are biodegradable, the more complex the molecular structure of the constituent, the more difficult and less rapid is biological treatment. Most low molecular-weight (nine carbon atoms or less) aliphatic and monoaromatic constituents are more easily biodegraded than higher molecular weight aliphatic or polyaromatic organic constituents. Exhibit IV-9 lists, in order of decreasing rate of potential biodegradability, some common constituents found at petroleum UST sites.

Exhibit IV-9
Chemical Structure And Biodegradability

Biodegradability	Example Constituents	Products In Which Constituent Is Typically Found
More degradable	n-butane, l-pentane, n-octane	❍ Gasoline
	Nonane	❍ Diesel fuel
	Methyl butane, dimethylpentenes, methyloctanes	❍ Gasoline
	Benzene, toluene, ethylbenzene, xylenes	❍ Gasoline
	Propylbenzenes	❍ Diesel, kerosene
	Decanes Dodecanes Tridecanes Tetradecanes	❍ Diesel ❍ Kerosene ❍ Heating fuels ❍ Lubricating oils
Less degradable	Naphthalenes Fluoranthenes Pyrenes Acenaphthenes	❍ Diesel ❍ Kerosene ❍ Heating oil ❍ Lubricating oils

Evaluation of the chemical structure of the constituents proposed for reduction by biopiles at the site will allow you to determine which constituents will be the most difficult to degrade. You should verify that remedial time estimates, biotreatability studies, field-pilot studies (if applicable), and biopile operation and monitoring plans are based on the constituents that are most difficult to degrade (or “rate limiting”) in the biodegradation process.

Concentration And Toxicity

The presence of very high concentrations of petroleum organics or heavy metals in site soils can be toxic or inhibit the growth and reproduction of bacteria responsible for biodegradation in biopiles. Conversely, very low concentrations of organic material will result in diminished levels of microbial activity.

In general, soil concentrations of total petroleum hydrocarbons (TPH) in the range of 10,000 to 50,000 ppm, or heavy metals exceeding 2,500 ppm, are considered inhibitory and/or toxic to most microorganisms. If TPH concentrations are greater than 10,000 ppm, or the concentration of heavy metals is greater than 2,500 ppm, then the contaminated soil should be thoroughly mixed with clean soil to dilute the contaminants so that the average concentrations are below toxic levels. Exhibit IV-10 provides the general criteria for constituent concentration and biopile effectiveness.

Exhibit IV-10
Constituent Concentration And Biopile Effectiveness

Constituent Concentration	Biopile Effectiveness
Petroleum constituents ≤ 50,000 ppm and Heavy metals ≤ 2,500 ppm	Effective, however, if contaminant concentration is > 10,000 ppm, then soil should be blended with clean soil to reduce the concentration of the contaminants.
Petroleum constituents > 50,000 ppm or Heavy metals > 2,500 ppm	Ineffective; toxic or inhibitory conditions to bacterial growth exist. Dilution by blending necessary.

In addition to maximum concentrations, you should consider the cleanup goals proposed for the biopile soils. Below a certain “threshold” constituent concentration, the bacteria cannot obtain sufficient carbon (from degradation of the constituents) to maintain adequate biological activity. The threshold level can be determined from laboratory studies and should be below the level required for cleanup. Although the threshold limit varies greatly depending on bacteria-specific and constituent-specific features, generally constituent concentrations below 0.1 ppm are not achievable by biological treatment alone. In addition, experience has shown that reductions in TPH concentrations greater than 95 percent can be very difficult to achieve because of the presence of “recalcitrant” or nondegradable hydrocarbon species that are included in the TPH analysis. If a cleanup level lower than 0.1 ppm is required for any individual constituent or a reduction in TPH greater than 95 percent is required to reach the cleanup level for TPH, either a pilot study is required to demonstrate the ability of a biopile system to achieve these reductions at the site or another technology should be considered. Exhibit IV-11 shows the relationship between cleanup requirements and biopile effectiveness.

Exhibit IV-11
Cleanup Requirements And Biopile Effectiveness

Cleanup Requirement	Biopile Effectiveness
Constituent concentration > 0.1 ppm and TPH reduction < 95%	Effective.
Constituent concentration ≤ 0.1 ppm or TPH reduction ≥ 95%	Potentially ineffective; pilot studies are required to demonstrate contaminant reductions.

Climatic Conditions

Ambient Temperature

The ambient temperature is important because it influences soil temperature. As described previously, the temperature of the soils in the biopile impacts bacterial activity and, consequently, biodegradation. The optimal temperature range for biopiles is 10°C to 45°C. Special considerations (e.g., heating, covering, or enclosing) in biopile design can overcome the effects of colder climates and extend the length of the bioremediation season.

Rainfall

Some biopile designs do not include covers, leaving the biopile exposed to climatic factors including rainfall, snow, and wind, as well as ambient temperatures. Rainwater that falls on the biopile area will increase the moisture content of the soil and cause erosion. As previously described, effective biopile operation requires a proper range of moisture content. During and following a significant precipitation event, the moisture content of the soils may be temporarily in excess of that required for effective bacterial activity. On the other hand, during periods of drought, moisture content may be below the effective range and additional moisture may need to be added.

If the site is located in an area subject to annual rainfall of greater than 30 inches during the biopile season, a rain shield (such as a cover, tarp, plastic tunnel, or greenhouse structure) should be considered in the design of the biopile. In addition, rainfall runon and runoff from the biopile area should be controlled using berms at the perimeter of the biopile. A leachate collection system at the bottom of the biopile and a leachate treatment system may also be necessary to prevent groundwater contamination from the biopile.

Wind

Erosion of the biopile soils can occur during windy periods. Wind erosion can be limited by applying moisture periodically to the surface of the biopile or by enclosing or covering the biopile.

Biotreatability Evaluation

Biotreatability studies are especially desirable if toxicity is a concern or natural soil conditions are not conducive to biological activity. Biotreatability studies are usually performed in the laboratory and should be planned so that, if successful, the proper parameters are developed to design and implement the biopile system. If biotreatability studies do not demonstrate effectiveness, field trials or pilot studies will be needed prior to implementation, or another remedial approach should be evaluated. If the soil, constituents, and climatic characteristics are within the range of effectiveness for biopiles, review biotreatability studies to confirm that biopiles have the potential for effectiveness and to verify that the parameters needed to design the full-scale biopile system have been obtained. Biotreatability studies should provide data on contaminant biodegradability, ability of indigenous microorganisms to degrade contaminants, optimal microbial growth conditions and biodegradation rates, and sufficiency of natural nutrients and minerals.

There are two types of biotreatability studies generally used to demonstrate biopile effectiveness: (1) Flask Studies and (2) Pan Studies. Both types of studies begin with the characterization of the baseline physical and chemical properties of the soils to be treated in the biopile. Typical physical and chemical analyses performed on site soil samples for biotreatability studies are listed on Exhibit IV-12. The specific objectives of these analyses are to:

- Determine the types and concentrations of contaminants in the soils that will be used in the biotreatability studies.

- Assess the initial concentrations of constituents present in the study samples so that reductions in concentration can be evaluated.

- Determine if nutrients (nitrogen and phosphorus) are present in sufficient concentrations to support enhanced levels of bacterial activity.

- Evaluate parameters that may inhibit bacterial growth (e.g., toxic concentrations of metals, pH values lower than 6 or higher than 8).

Exhibit IV-12
Physical And Chemical Parameters For Biotreatability Studies

Parameter	Measured Properties
Soil toxicity	Type and concentration of contaminant and/or metals present, pH.
Soil texture	Grain size, clay content, moisture content, porosity, permeability, bulk density.
Nutrients	Nitrate, phosphate, other anions and cations.
Contaminant biodegradability	Total organic carbon concentration, volatility, chemical structure.

After you have characterized the soil samples, perform bench studies to evaluate biodegradation effectiveness. Flask (or bottle) studies which are simple and inexpensive, are used to test for biodegradation in water or soils using soil/water slurry microcosms. Flask studies may use a single slurry microcosm that is sampled numerous times or may have a series of slurry microcosms, each sampled once. Flask studies are less desirable than pan studies for evaluation of biopile effectiveness and are primarily used for evaluation of water-phase bioremedial technologies. Pan studies use soils, without dilution in an aqueous slurry, placed in steel or glass pans as microcosms that more closely resemble biopiles.

In either pan or flask studies, degradation is measured by tracking constituent concentration reduction and changes in bacterial population and other parameters over time. A typical treatment evaluation using pan or flask studies may include the following types of studies.

❍ *No Treatment Control Studies* measure the rate at which the existing bacteria can degrade constituents under oxygenated conditions without the addition of supplemental nutrients.

❍ *Nutrient Adjusted Studies* determine the optimum adjusted C:N:P ratio to achieve maximum degradation rates using microcosms prepared with different concentrations of nutrients.

❍ *Inoculated Studies* are performed if bacterial plate counts indicate that natural microbial activity is insufficient to promote sufficient degradation. Microcosms are inoculated with bacteria known to degrade the constituents at the site and are analyzed to determine if degradation can be increased by inoculation.

- *Sterile Control Studies* measure the degradation rate due to abiotic processes (including volatilization) as a baseline comparison with the other studies that examine biological processes. Microcosm soils are sterilized to eliminate bacterial activity. Abiotic degradation rates are then measured over time.

Review the CAP to determine that biotreatability studies have been completed, biodegradation is demonstrated, nutrient application and formulation have been evaluated and defined, and potential inhibitors or toxic conditions have been identified.

Evaluation Of The Biopile Design

Once you have verified that biopiles have the potential to be effective, you can evaluate the design of the biopile system. The CAP should include a discussion of the rationale for the design and present the conceptual engineering design. Detailed engineering design documents might also be included, depending on state requirements. Further detail about information to look for in the discussion of the design is provided below.

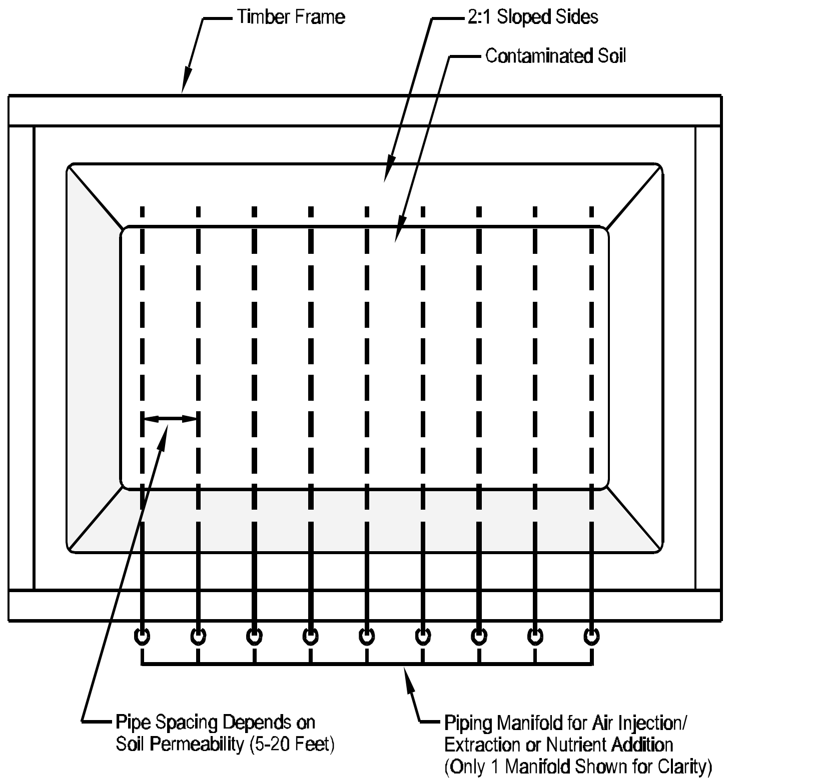
- *Land Requirements* can be determined by dividing the amount of soil to be treated by the height of the proposed biopile(s). The typical height of biopiles varies between 3 and 10 feet. Additional land area around the biopile(s) will be required for sloping the sides of the pile, for containment berms, and for access. The length and width of biopiles is generally not restricted unless aeration is to occur by manually turning the soils. In general, biopiles which will be turned should not exceed 6 to 8 feet in width.

- *Biopile Layout* is usually determined by the configuration of and access to the land available for the biopile(s). The biopile system can include single or multiple piles.

- *Biopile Construction* includes: site preparation (grubbing, clearing, and grading); berms; liners and covers(if necessary); air injection, extraction and/or collection piping arrangement; nutrient and moisture injection piping arrangement; leachate collection and treatment systems; soil pretreatment methods (e.g., shredding, blending, amendments for fluffing, pH control); and enclosures and appropriate vapor treatment facilities (where needed). The construction design of a typical biopile is shown as Exhibit IV-13.

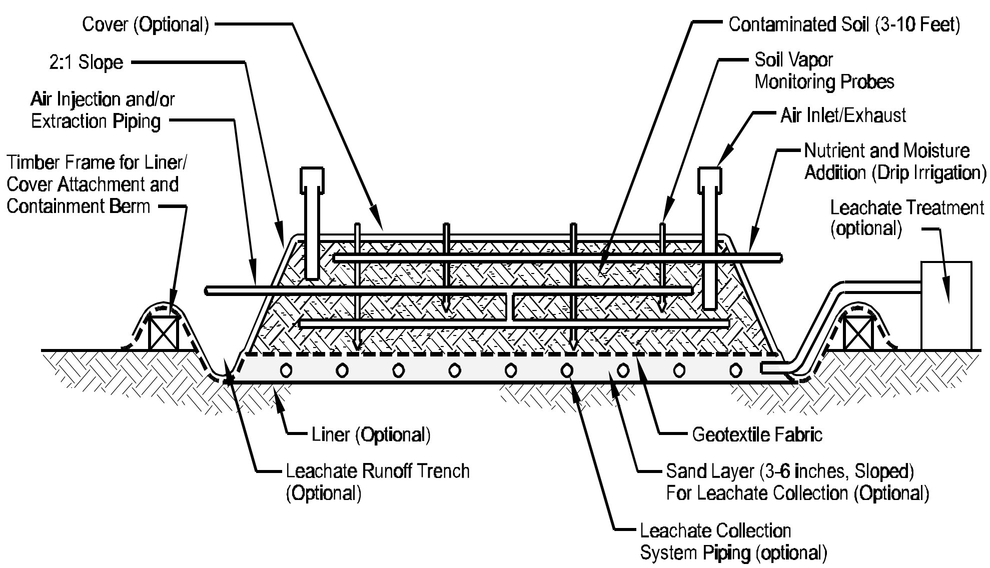
- *Aeration Equipment* usually includes blowers or fans which will be attached to the aeration piping manifold unless aeration is to be accomplished by manually turning the soil.

Exhibit IV-13
Construction Design Of A Typical Biopile



PLAN VIEW

NOT TO SCALE



CROSS SECTION

NOT TO SCALE

- *Water Management* systems for control of runon and runoff are necessary to avoid saturation of the treatment area or washout of the soils in the biopile area. Runon is usually controlled by earthen berms or ditches that intercept and divert the flow of stormwater. Runoff can be controlled by diversion within the bermed treatment area to a retention pond where the runoff can be stored, treated, or released under a National Pollution Discharge Elimination System (NPDES) permit.

- *Soil Erosion Control* from wind or water generally includes sloping the sides of the pile, covering the pile, constructing water management systems, and spraying to minimize dust.

- *pH Adjustment, Moisture Addition, and Nutrient Supply* methods usually include incorporation of solid fertilizers, lime and/or sulfur into the soils while constructing the biopile, or injection of liquid nutrients, water and acid/alkaline solutions preferably through a dedicated piping system during operation of the biopile. The composition of nutrients and acid or alkaline solutions/solids for pH control is developed in biotreatability studies, and the frequency of their application is modified during biopile operation as needed.

- *Site Security* may be necessary to keep trespassers out of the treatment area. If the biopile is accessible to the public, a fence or other means of security is recommended to deter public contact with the contaminated material within the biopile area.

- *Air Emission Controls* (e.g., covers or structural enclosures) may be required if volatile constituents are present in the biopile soils. For compliance with air quality regulations, the volatile organic emissions should be estimated based on initial concentrations of the petroleum constituents present. Vapors in extracted or injected air should be monitored during the initial phases of biopile operation for compliance with appropriate permits or regulatory limits on atmospheric discharges. If required, appropriate vapor treatment technology should be specified, including operation and monitoring parameters.

Evaluation Of Operation And Remedial Progress Monitoring Plans

It is important to make sure that system operation and monitoring plans have been developed for the biopile operation. Regular monitoring is necessary to ensure optimization of biodegradation rates, to track constituent concentration reductions, and to monitor vapor emissions, migration of constituents into soils beneath the biopile (if unlined), and groundwater quality. If appropriate, ensure that monitoring to determine compliance with stormwater discharge or air quality permits is also proposed.

Operations Plan

Make certain that the plan for operating the biopile system described in the CAP includes the anticipated frequency of aeration, nutrient addition, and moisture addition. The plan should be flexible and modified based on the results of regular monitoring of the biopile soils. The plan should also account for seasonal variations in ambient temperature and rainfall. In general, aeration and moisture and nutrient applications should be more frequent in the warmer, drier months. If the biopile is covered with impervious sheeting (e.g., plastic or geofabric/geotextile), the condition of the cover must be checked periodically to ensure that it remains in place and that it is free of rips, tears, or other holes. Provision should be made for replacement of the cover in the event that its condition deteriorates to the point where it is no longer effective.

Remedial Progress Monitoring Plan

Make certain that the monitoring plan for the biopile system is described in detail and include monitoring of biopile soils for constituent reduction and biodegradation conditions (e.g., CO_2, O_2, CH_4, H_2S), air monitoring for vapor emissions if volatile constituents are present, soil and groundwater monitoring to detect potential migration of constituents beyond the biopile area, and runoff water sampling (if applicable) for discharge permits. Make sure that the number of samples collected, sampling locations, and collection methods are in accordance with state regulations. A monitoring plan for a typical biopile operation is shown in Exhibit IV-14.

Soils within the biopile should be monitored at least quarterly during treatment to determine pH, moisture content, bacterial population, nutrient content, and constituent concentrations. For biopiles using air extraction or for those using air injection and off-gas collection, biodegradation conditions can be tracked by measuring oxygen and carbon dioxide concentrations in the vapor extracted from the biopile. These measurements should be taken weekly during the first 3 months of operation. The results of these analyses, which may be done using electronic instruments, field test kits, or in a field laboratory are critical to the optimal operation of the biopile. The results should be used to adjust air injection or extraction flow rates, nutrient application rates, moisture addition frequency and quantity, and pH. Optimal ranges for these parameters should be maintained to achieve maximum degradation rates.

Exhibit IV-14
Typical Remedial Progress Monitoring Plan For Biopiles

Medium To Be Monitored	Purpose	Sampling Frequency	Parameters To Be Analyzed
Soil in the biopile	Determine constituent degradation and biodegradation conditions.	Monthly to quarterly during the operation.	Bacterial population, constituent concentrations, pH, ammonia, phosphorus, moisture content, other rate limiting conditions.
Air extracted or collected from the biopile	Determine constituent degradation and biodegradation conditions.	Weekly during the first 3 months then monthly or quarterly.	CO_2, O_2, CH_4, H_2S, VOCs.
Air	Site personnel and population health hazards.	Twice during the first two weeks of operation, quarterly thereafter or to meet air quality requirements.	Volatile constituents, particulates.
Runoff water	Soluble or suspended constituents.	As required for NPDES permit.	As specified for NPDES permit; also hazardous organics.
Soil beneath the biopile	Migration of constituents.	Quarterly or twice per biopile season.	Hazardous constituents.
Groundwater downgradient of biopile	Migration of soluble constituents.	Once per biopile season (annually).	Hazardous, soluble constituents.

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Checklist: Can Biopiles Be Used At This Site?

This checklist can help you to evaluate to completeness of the CAP and to identify areas that require closer scrutiny. As you go through the CAP, answer the following questions. If the answer to several questions is no and biotreatability studies demonstrate marginal to ineffective results, request additional information to determine if biopiles will accomplish cleanup goals at the site.

1. Soil Characteristics That Contribute To Biopile Effectiveness

Yes No

❑ ❑ Is the total heterotrophic bacteria count > 1,000 CFU/gram dry soil?

❑ ❑ Is the soil pH between 6 and 8?

❑ ❑ Is the soil moisture between 40% and 85%?

❑ ❑ Is the soil temperature between 10°C and 45°C?

❑ ❑ Is the carbon:nitrogen:phosphorous ratio between 100:10:1 and 100:1:0.5?

❑ ❑ Does the soil divide easily and tend not to clump together?

2. Constituent Characteristics That Contribute To Biopile Effectiveness

Yes No

❑ ❑ Are products to be treated primarily kerosene or heavier (i.e., not gasoline), or will air emissions be monitored and, if necessary, controlled?

❑ ❑ Are most of the constituents readily degradable?

❑ ❑ Are total petroleum constituents $\leq$ 50,000 ppm and total heavy metals $\leq$ 2,500 ppm?

3. Climatic Conditions That Contribute To Biopile Effectiveness

Yes No

❑ ❑ Is the rainfall less than 30 inches during the biopile season?

❑ ❑ Are high winds unlikely?

4. Biotreatability Evaluation

Yes No

- ❑ ❑ Has a biotreatability study been conducted?
- ❑ ❑ Was biodegradation demonstrated, nutrient application and formulation defined, and potential inhibitors or toxic conditions checked?

5. Evaluation Of Biopile Design

Yes No

- ❑ ❑ Is sufficient land available considering the biopile depth and additional space for berms and access?
- ❑ ❑ Is runon and runoff controlled?
- ❑ ❑ Are erosion control measures specified?
- ❑ ❑ Are the frequency of application and composition of nutrients and pH adjustment materials specified?
- ❑ ❑ Is moisture addition needed?
- ❑ ❑ Are other sub-optimal natural site conditions addressed in the biopile design (e.g., low temperatures, poor soil texture, and excessive rainfall)?
- ❑ ❑ Is the site secured?
- ❑ ❑ Are air emissions estimated and will air emissions monitoring be conducted?
- ❑ ❑ Are provisions included for air emissions controls, if needed?

6. Operation And Monitoring Plans

Yes No

- ❑ ❑ Are frequencies of aeration, nutrient addition, and moisture addition provided in the operation plan?
- ❑ ❑ Is monitoring for constituent reduction and biodegradation conditions proposed?

6. Operation And Monitoring Plans (continued)

Yes No

- ❑ ❑ Are air, soil, and surface runoff water sampling (if applicable) proposed to ensure compliance with appropriate permits?

- ❑ ❑ Are the proposed number of samples to be collected, sampling locations, and collection methods in accordance with state regulations?

- ❑ ❑ Is quarterly (or more frequent) monitoring for soil pH, moisture content, bacterial population, nutrient content, and constituent concentrations proposed?