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How To Evaluate Alternative Cleanup Technologies For Underground Storage Tank Sites

A Guide For Corrective Action Plan Reviewers

Chapter V

Landfarming

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Chapter V
Landfarming

Overview

Landfarming, also known as land treatment or land application, is an above-ground remediation technology for soils that reduces concentrations of petroleum constituents through biodegradation. This technology usually involves spreading excavated contaminated soils in a thin layer on the ground surface and stimulating aerobic microbial activity within the soils through aeration and/or the addition of minerals, nutrients, and moisture. The enhanced microbial activity results in degradation of adsorbed petroleum product constituents through microbial respiration. If contaminated soils are shallow (i.e., $\leq$ 3 feet below ground surface), it may be possible to effectively stimulate microbial activity without excavating the soils. If petroleum-contaminated soil is deeper than 5 feet, the soils should be excavated and reapplied on the ground surface. A typical landfarming operation is shown in Exhibit V-1.

Landfarming has 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 landfarm aeration processes (i.e., tilling or plowing) 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 landfarm 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 landfarming is shown in Exhibit V-2.

The policies and regulations of your state determine whether landfarming is allowed as a treatment option. Before reading this chapter, consider whether your state allows the use of this remedial option.

Exhibit V-1
Typical Landfarming Operation

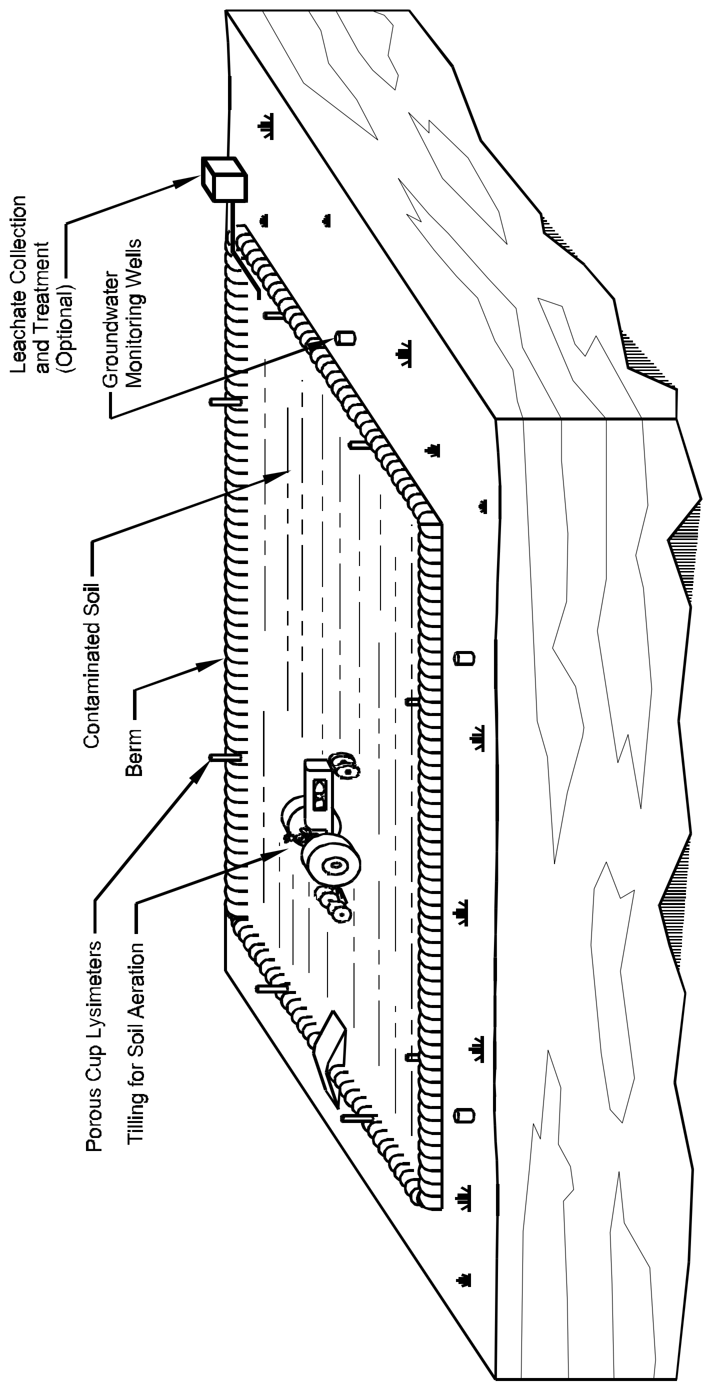


Exhibit V-2
Advantages And Disadvantages Of Landfarming

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: $30-60/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 a large land area for treatment.
	❍ Dust and vapor generation during landfarm aeration may pose air quality concerns.
	❍ May require bottom liner if leaching from the landfarm is a concern.

This chapter will assist you in evaluating a corrective action plan (CAP) that proposes landfarming as a remedy for petroleum contaminated soil. The evaluation guidance is presented in the three steps described below. The evaluation process, which is summarized in a flow diagram shown in Exhibit V-3, will serve as a roadmap for the decisions you will make during your evaluation. A checklist has also been provided at the end of this chapter to be used as a tool to evaluate the completeness of the CAP and to help you focus on areas where additional information may be needed. The evaluation process can be divided into the following steps.

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

Exhibit V-3
Landfarming Evaluation Process Flow Chart

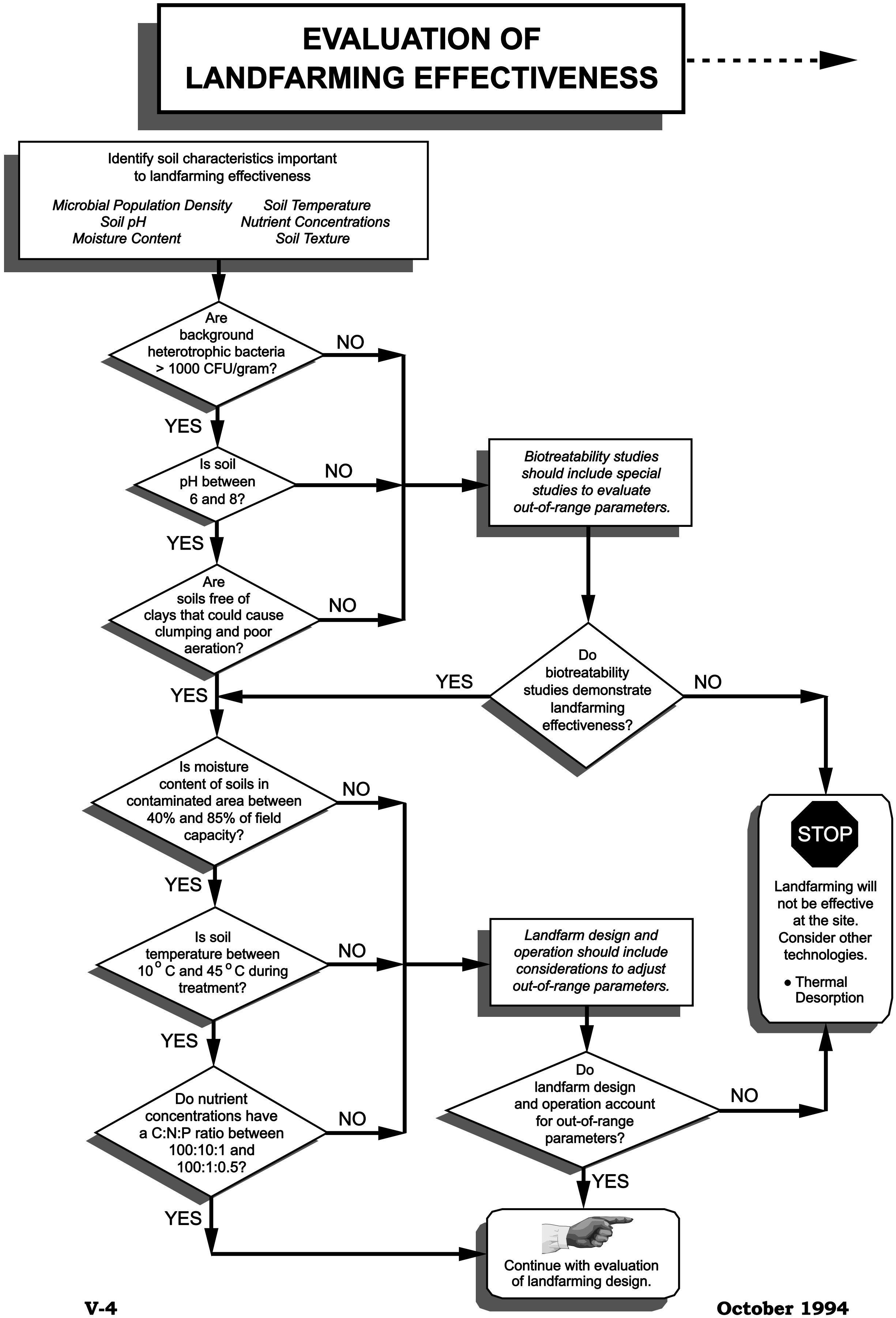


Exhibit V-3
Landfarming Evaluation Process Flow Chart

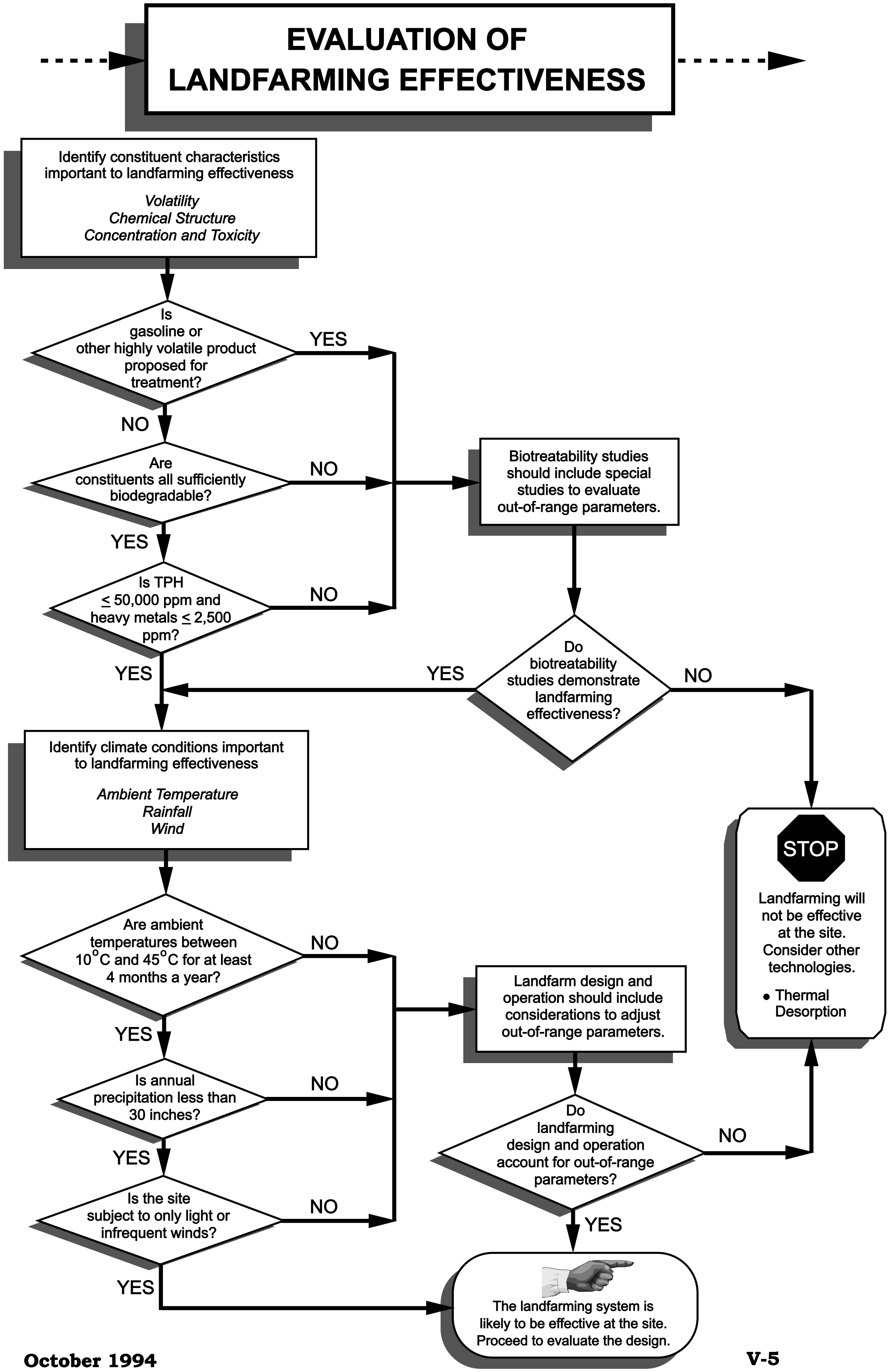
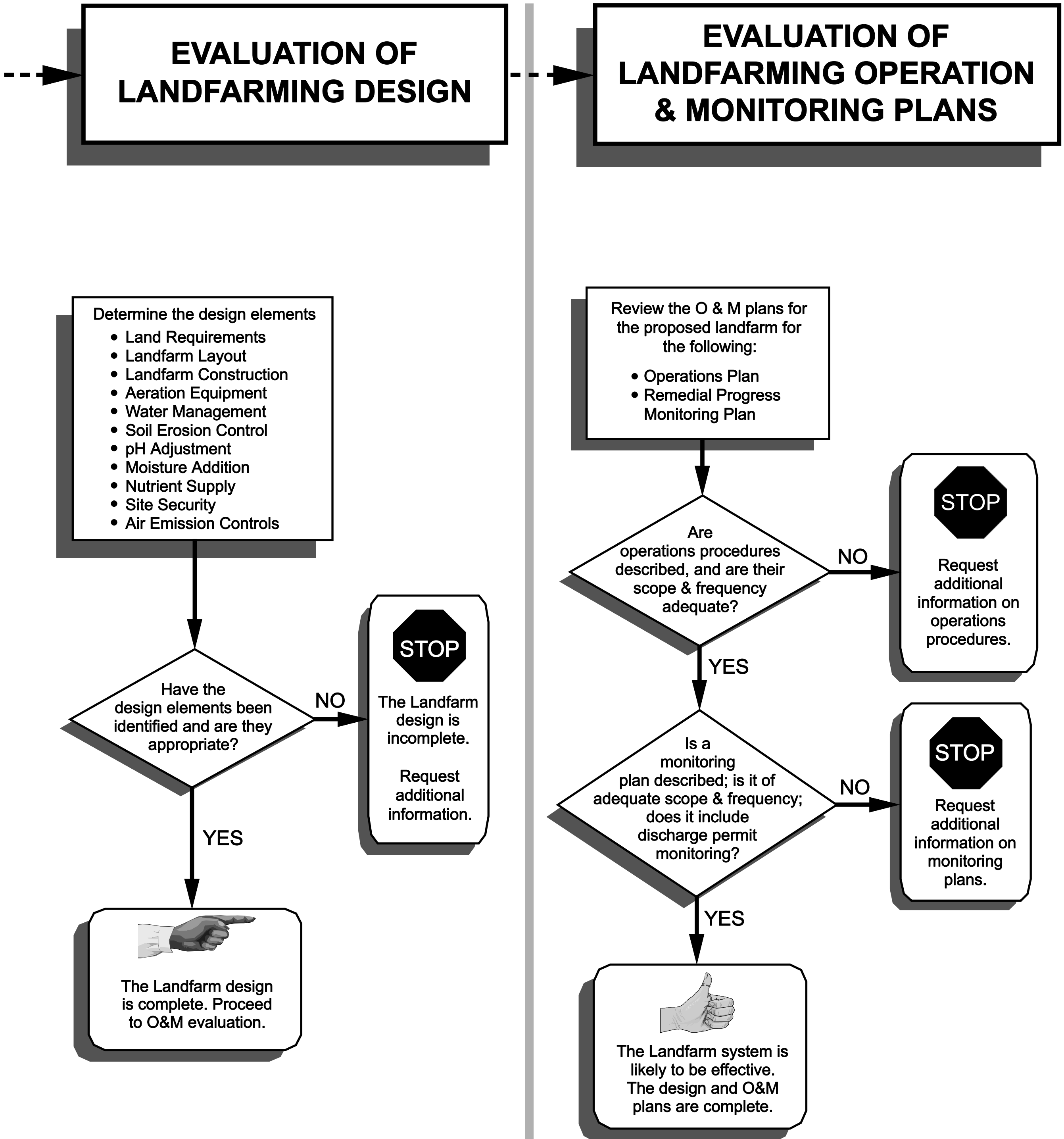


Exhibit V-3
Landfarming Evaluation Process Flow Chart



- **Step 2: *An evaluation of the landfarming 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 landfarming, will allow you to determine whether start-up and long-term system operation and monitoring plans are of sufficient scope and frequency.

Evaluation Of Landfarming Effectiveness

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

Exhibit V-4
Parameters Used To Evaluate The Effectiveness Of Landfarming

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		
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 landfarming is an above-ground treatment technique, most parameters (except climatic conditions) can be controlled during the design and operation of the landfarm. Therefore, during your evaluation, identify those parameters that fall outside the effectiveness 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 landfarming, 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, 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.

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 landfarming applications directed at 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 landfarming 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, landfarming 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 or not 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 vendors. Exhibit V-5 shows the relationship between plate counts of total heterotrophic bacteria and the effectiveness of landfarming.

Exhibit V-5
Heterotrophic Bacteria And Landfarming Effectiveness

Total Heterotrophic Bacteria (prior to landfarming)	Landfarming Effectiveness
> 1000 CFU/gram dry soil	Generally effective.
< 1000 CFU/gram dry soil	May be effective; needs further evaluation to determine if toxic conditions are present.

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 landfarming will require pH adjustment prior to and during landfarming operations. Soil pH within the landfarm can be raised through the addition of lime and lowered by adding elemental sulfur. Exhibit V-6 summarizes the effect of soil pH on landfarming 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 design and operational plans for the landfarm.

Exhibit V-6
Soil pH And Landfarming Effectiveness

Soil pH (prior to landfarming)	Landfarming Effectiveness
$6 \leq pH \leq 8$	Generally effective.
$6 > pH > 8$	Landfarm soils will require amendments to correct pH to effective range.

Moisture Content

Soil microorganisms require moisture for proper growth. Excessive soil moisture, however, restricts the movement of air through the subsurface thereby reducing the availability of oxygen which is also necessary for aerobic bacterial metabolic processes. In general, the soil 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 in landfarming operations because soils become dry as a result of evaporation, which is increased during aeration operations (i.e., tilling and/or plowing). Excessive accumulation of moisture can occur at landfarms in areas with high precipitation or poor drainage. These conditions should be considered in the landfarm design. For example, an impervious cover can mitigate excessive infiltration and potential erosion of the landfarm. Exhibit V-7 shows the optimal range for soil moisture content.

Exhibit V-7
Soil Moisture And Landfarming Effectiveness

Soil Moisture	Landfarming Effectiveness
40% $\leq$ field capacity $\leq$ 85%	Effective.
Field capacity < 40%	Periodic moisture addition is needed to maintain proper bacterial growth.
Field capacity > 85%	Landfarm design should include special water drainage considerations.

Soil Temperature

Bacterial growth rate is a function of temperature. Soil microbial activity has been shown to decrease significantly 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 temperatures, 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. The period of the year when the ambient temperature is within the range for microbial activity is commonly called the “landfarming season.”

In colder parts of the United States, such as the Northeastern states, the length of the landfarming season is shorter, typically ranging from only 7 to 9 months. In very cold climates, special precautions can be taken, including enclosing the landfarm within a greenhouse-type structure or introducing special bacteria (psychrophiles), which are capable of activity at lower temperatures. In warm regions, the landfarming season can last all year. Exhibit V-8 shows how soil temperature affects landfarming operation.

Exhibit V-8
Soil Temperature And Landfarming Effectiveness

Soil Temperature	Landfarming Effectiveness
$10°C \leq$ soil temperature $\leq 45°C$	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 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 landfarm 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 upon 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 addition can lower 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 tilling or plowing), 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 which 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 landfarming at the site. Soil amendments (e.g., gypsum) and bulking materials (e.g., sawdust, or straw) should be blended into the soil as the landfarm is being constructed to ensure that the landfarming medium has a loose or divided texture. Clumpy soil may require shredding or other means of pretreatment during landfarm construction to incorporate these amendments.

Constituent Characteristics

Volatility

The volatility of contaminants proposed for treatment by landfarming is important because volatile constituents tend to evaporate from the landfarm, particularly during tilling or plowing operations, rather than being biodegraded by bacteria. Constituent vapors emitted from a landfarm will dissipate into the atmosphere unless the landfarm is enclosed within a surface structure such as a greenhouse or plastic tunnel or covered with a plastic sheet.

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 landfarm. 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 landfarming 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 V-9 lists, in order of decreasing rate of potential biodegradability, some common constituents found at petroleum UST sites.

Evaluation of the chemical structure of the constituents proposed for reduction by landfarming 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 landfarm operation and monitoring plans are based on the constituents that are most difficult to degrade (or “rate limiting”) in the biodegradation process.

Exhibit V-9
Chemical Structure And Biodegradability

Biodegradability	Example Constituents	Products In Which Constituent Is Typically Found
More degradable	n-butane, n-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

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 landfarms. In addition, very low concentrations of organic material will also result in diminished levels of bacteria 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 V-10 provides the general criteria for constituent concentration and landfarming effectiveness.

Exhibit V-10
Constituent Concentration And Landfarming Effectiveness

Constituent Concentration	Landfarming Effectiveness
Petroleum constituents ≤ 50,000 ppm and Heavy metals ≤ 2,500 ppm	Effective; however, if contaminant concentration is > 10,000 ppm, the soil may need to 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 landfarm 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 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 landfarming to achieve these reductions at the site or another technology should be considered. Exhibit V-11 shows the relationship between cleanup requirements and landfarming effectiveness.

Climatic Conditions

Typical landfarms are uncovered and, therefore, exposed to climatic factors including rainfall, snow, and wind, as well as ambient temperatures.

Ambient Temperature

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

Exhibit V-11
Cleanup Requirements And Landfarming Effectiveness

Cleanup Requirement	Landfarming 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 reduction.

Rainfall

Rainwater that falls directly onto, or runs onto, the landfarm area will increase the moisture content of the soil and cause erosion. As previously described, effective landfarming 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 landfarming season, a rain shield (such as a tarp, plastic tunnel, or greenhouse structure) should be considered in the design of the landfarm. In addition, rainfall runon and runoff from the landfarm should be controlled using berms at the perimeter of the landfarm. A leachate collection system at the bottom of the landfarm and a leachate treatment system may also be necessary to prevent groundwater contamination from the landfarm.

Wind

Erosion of landfarm soils can occur during windy periods and particularly during tilling or plowing operations. Wind erosion can be limited by plowing soils into windrows and applying moisture periodically.

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 landfarming approach. 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 landfarming, review biotreatability studies to confirm that landfarming has the potential for effectiveness and to verify that the parameters needed to design the full-scale landfarm 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 landfarming 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 landfarm. Typical physical and chemical analyses performed on site soil samples for biotreatability studies are listed on Exhibit V-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).

After the characterization of the soil samples is complete, 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 landfarming 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 landfarming.

Exhibit V-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.

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 no potential inhibitors or toxic conditions have been identified.

Evaluation Of The Landfarm Design

Once you have verified that landfarming has the potential for effectiveness, you can evaluate the design of the landfarm. 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 depth of the landfarm soils. The depth of landfarms can vary between 12 inches and 18 inches depending on the capabilities of the tilling equipment to be used. Very powerful tillers can reach as much as 24 inches deep to aerate landfarm soils. Additional land area around the landfarm will be required for containment berms and for access.

❍ *Landfarm Layout* is usually determined by the configuration of and access to the land available for the landfarm. The landfarm can include single or multiple plots.

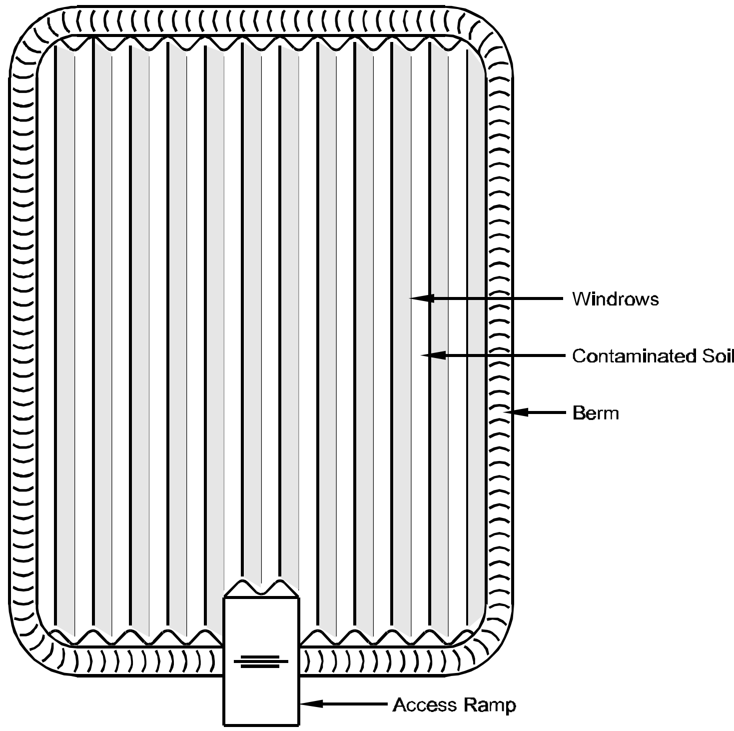
❍ *Landfarm Construction* includes: site preparation (grubbing, clearing and grading); berms; liners (if necessary); leachate collection and treatment systems; soil pretreatment methods (e.g., shredding, blending and amendments for fluffing, pH control); and enclosures and appropriate vapor treatment facilities (where needed). The construction design of a typical landfarm is shown as Exhibit V-13.

❍ *Aeration Equipment* usually includes typical agricultural equipment such as roto-tillers. The most favorable method is to use a disking device towed behind a tractor so that aerated soils are not tamped by the tractor tires.

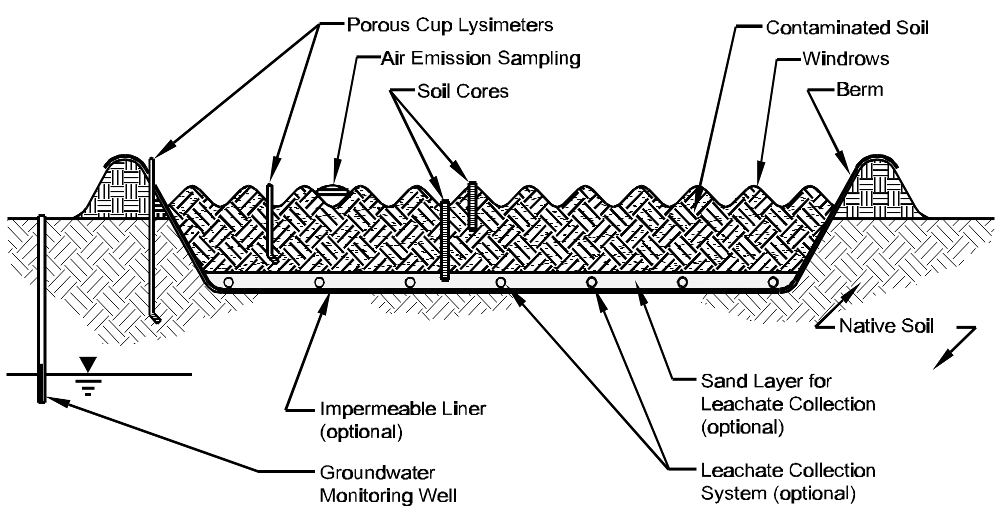
❍ *Water Management* systems for control of runon and runoff are necessary to avoid saturation of the treatment area or washout of the soils in the landfarm. Runon is usually controlled by earthen berms or ditches that intercept and divert the flow of stormwater. Runoff can be controlled by diversion 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 terracing the soils into windrows, constructing water management systems, and spraying to minimize dust.

Exhibit V-13
Construction Design Of A Typical Landfarm



PLAN VIEW
NOT TO SCALE



CROSS SECTION
NOT TO SCALE

- *pH Adjustment and Nutrient Supply* methods usually include periodic application of solid fertilizers, lime and/or sulfur while disking to blend soils with the solid amendments, or applying liquid nutrients using a sprayer. 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 landfarm operation as needed.

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

- *Air Emission Controls* (e.g., covers or structural enclosures) may be required if volatile constituents are present in the landfarm soils. For compliance with air quality regulations, the volatile organic emissions should be estimated based on initial concentrations of the petroleum constituents present. Vapors above the landfarm should be monitored during the initial phases of landfarm 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 landfarming 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 landfarm (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 landfarm 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 landfarm 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 landfarm is covered with impervious sheeting (e.g., plastic or geofabric/textile), 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. Particularly in the more northern states, operations may be suspended altogether during the winter months.

Remedial Progress Monitoring Plan

Make certain that the monitoring plan for the landfarm is described in detail and includes monitoring of landfarm 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 landfarm, 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 landfarm operation is shown in Exhibit V-14.

Soils within the landfarm should be monitored at least quarterly during the landfarming season to determine pH, moisture content, bacterial population, nutrient content, and constituent concentrations. 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 landfarm. The results should be used to adjust aeration frequency, nutrient application rates, moisture addition frequency and quantity, and pH. Optimal ranges for these parameters should be maintained to achieve maximum degradation rates.

Exhibit V-14
Typical Remedial Progress Monitoring Plan For Landfarming

Medium To Be Monitored	Purpose	Sampling Frequency	Parameters To Be Analyzed
Soil in the landfarm	Determine constituent degradation and biodegradation conditions.	Monthly to quarterly during the landfarming season.	Bacterial population, constituent concentrations, pH, ammonia, phosphorus, moisture content, other rate limiting conditions.
Air	Site personnel and population health hazards.	During first two aerations, 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 landfarm	Migration of constituents.	Quarterly or twice per landfarming season.	Hazardous constituents.
Groundwater downgradient of landfarm	Migration of soluble constituents.	Once per landfarming season (annually).	Hazardous, soluble constituents.

References

Alexander, M. *Biodegradation and Bioremediation*. San Diego, CA: Academic Press, 1994.

Flathman, P.E. and D.E. Jerger. *Bioremediation Field Experience*. Boca Raton, FL: CRC Press, 1993.

Freeman, H.M. *Standard Handbook of Hazardous Waste Treatment and Disposal*. New York, NY: McGraw-Hill Book Company, 1989.

Grasso, D. *Hazardous Waste Site Remediation, Source Control*. Boca Raton, FL: CRC Press, 1993.

Norris, R.D., Hinchee, R.E., Brown, R.A., McCarty, P.L., Semprini, L., Wilson, J.T., Kampbell, D.H., Reinhard, M., Bower, E.J., Borden, R.C., Vogel, T.M., Thomas, J.M., and C.H. Ward. *Handbook of Bioremediation*. Boca Raton, FL:CRC Press, 1994.

Norris, R.D., Hinchee, R.E., Brown, R.A., McCarty, P.L., Semprini, L., Wilson, J.T., Kampbell, D.H., Reinhard, M., Bower, E.J., Borden, R.C., Vogel, T.M., Thomas, J.M., and C.H. Ward. *In-Situ Bioremediation of Ground Water and Geological Material: A Review of Technologies*. Ada, OK: U.S. Environmental Protection Agency, Office of Research and Development. EPA/5R-93/124, 1993.

Pope, Daniel F., and J.E. Matthews. *Environmental Regulations and Technology: Bioremediation Using the Land Treatment Concept*. Ada, OK: U.S. Environmental Protection Agency, Environmental Research Laboratory. EPA/600/R-93/164, 1993.

Checklist: Can Landfarming Be Used At This Site?

This checklist can help you to evaluate the 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 landfarming will accomplish cleanup goals at the site.

1. Soil Characteristics That Contribute To Landfarming 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 Landfarming 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 ≤ 50,000 ppm and total heavy metals ≤ 2,500 ppm?

3. Climatic Conditions That Contribute To Landfarming Effectiveness

Yes No

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

❑ ❑ Are high winds unlikely?

4. Biotreatability Evaluation

Yes No

❑ ❑ Has a biotreatability study been conducted?

❑ ❑ Were biodegradation demonstrated, nutrient application and formulation defined, and potential inhibitors or toxic conditions checked?

5. Evaluation Of Landfarm Design

Yes No

❑ ❑ Is sufficient land available considering the landfarm depth and additional space for berms and access?

❑ ❑ Are 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 landfarm design?

❑ ❑ 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

❑ ❑ Is monitoring for stormwater discharge or air quality permits (if applicable) proposed?

❑ ❑ Does the operation plan include the anticipated frequency of aeration, nutrient addition, and moisture addition?

❑ ❑ Does the monitoring plan propose measuring constituent reduction and biodegradation conditions in the landfarm soils?

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 numbers of samples to be collected, sampling locations, and collected 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?