

Soil washing/flushing, SVE, Bioventing, Biopile, Landfarming

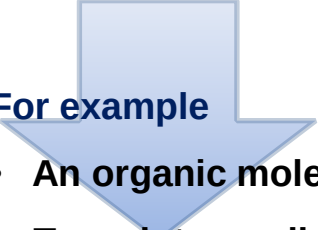
2010. 11. 12.



Hanyang University

Objective of Chemical Oxidation

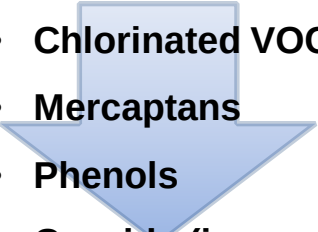
To detoxify waste by adding an oxidizing agent to chemically transform waste components



For example

- An organic molecule can be converted to carbon dioxide and water
- To an intermediate product that may be less toxic than original

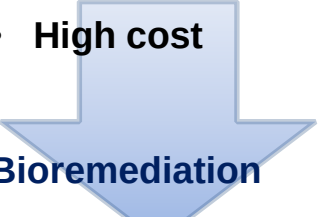
To be capable of destroying a wide range of organic molecules

- 
- Chlorinated VOC
 - Mercaptans
 - Phenols
 - Cyanide (inorganics)

Advantages of Chemical Oxidation

Incineration

- To produce air pollution
- High cost



Bioremediation

- Limitation of high toxicity pollutant
- To require long remediation time
- Possibility of generation of byproduct



Physical treatment

- Air stripping
- Carbon Adsorption
- Thermal Methods

Kinds of Chemical Oxidation

Advanced Oxidation Processes(AOPs)

Fenton reaction

- Classic Fenton reaction

Fenton-like process

- Modified Fenton reaction

Photoassited Fenton reaction

- $\text{H}_2\text{O}_2/\text{Fe}^{2+}$ or Fe^{3+}/UV
- $\text{H}_2\text{O}_2/\text{Fe}^{3+}$ -oxalate/UV
- Mn^{2+} /oxalic acid/Ozone

Photocatalysis

- $\text{TiO}_2/h\nu/\text{O}_2$
- $\text{O}_3/\text{H}_2\text{O}_2$
- O_3/UV
- $\text{H}_2\text{O}_2/\text{UV}$

Potassium permanganate

Classic Fenton reaction (AOPs)

Discovered by H.J.H Fenton (1894)

Fenton's reagent

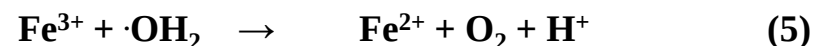
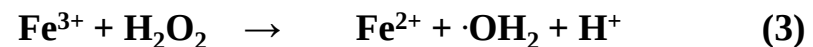
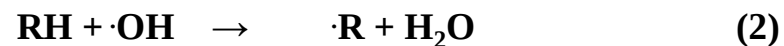
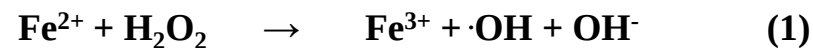
- Fe^{2+} (ferrous ion)
- H_2O_2 (hydrogen peroxide)

Production of $\cdot\text{OH}$ by Fenton reaction

Attractive oxidative system

- Iron is very abundant and non toxic element
- Hydrogen peroxide is easy to handle and environmentally safe

Optimum pH : 2~4



Modified Fenton reaction (Fenton-like Process ; AOPs)

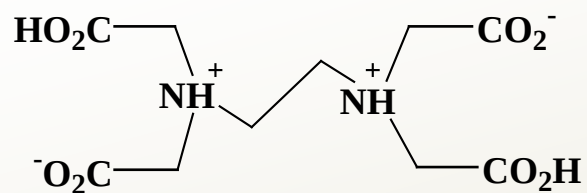
To overcome the limitation of Classic Fenton reaction

- **Precipitation of iron ion at neutral pH**

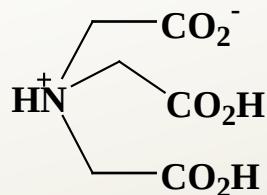
Iron catalysts chelated with organic ligands(chelating agents)

- To maintain iron stability at neutral pH
- Appropriate process for in-situ application
- Organic ligands (chelating agents)
 - ✓ Ethylenediaminetetraacetic acid (EDTA)
 - ✓ Nitrilotriacetic acid (NTA)
 - ✓ Sodium oxalate

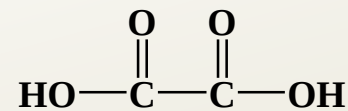
Chelating Agents



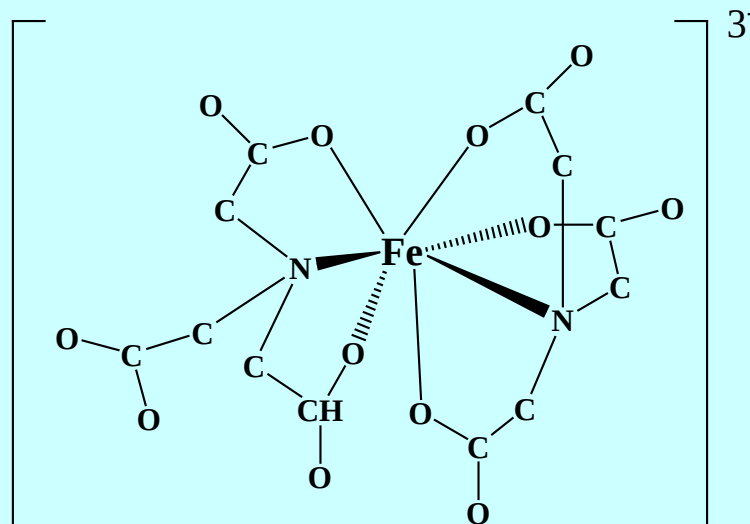
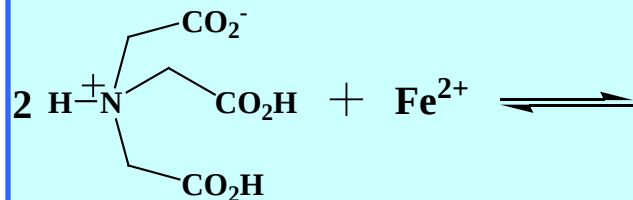
EDTA



NTA



Oxalate

Structure of $\text{Fe}(\text{NTA})_2^{3-}$ 

Modified Fenton reaction (Fenton-like Process ; AOPs)

Table I. Chelating Ability of Ligands for Iron(III) at pH 6 and Activity of the Chelates with Respect to Oxidation of 2,4-D by H_2O_2 ^a

ligand	soluble?	activity
aminopolycarboxylates		
EDTA	yes	inactive
HEDTA	yes	inactive
EDDHA	yes	inactive
EGTA	yes	inactive
NTA	yes	high
HEIDA	yes	high
polycarboxylates		
citric acid	yes ^b	low
malic acid	yes	moderate
l-malic acid	yes	moderate
ketomalonic acid	yes ^b	low
nt-tartaric acid	yes	low
oxalic acid	yes ^b	low
hydroxamates		
acetohydroxamic acid	yes ^b	inactive
violaric acid	no ^b	nt ^c
N-heterocyclic carboxylates		
picolinic acid	yes	high
dipicolinic acid	yes	moderate
pyrazinecarboxylic acid	no ^b	nt
oxonic acid	no ^b	nt
5-nitrooxonic acid	no ^b	nt
polyhydroxy aromatics		
catechol	yes	moderate
1,2-dihydroxybenzoic acid	yes	moderate
gallic acid	yes	high
quercetin	yes	moderate
rutin	yes	inactive
pyrocatechol violet	yes	moderate
alizarin red	yes	low
porphyrins		
hemin	yes	inactive
hematin	yes	inactive
hematoporphine X	yes	inactive
sulfur compounds		
pyrosulfate	no ^b	nt
dithionate	no ^b	nt
phosphates		
pyrophosphate	yes	inactive
hypophosphate	yes ^b	inactive
tripolyphosphate	yes	inactive
trimetaphosphate	yes ^b	inactive
phytate	yes ^b	inactive
imidodiphosphate	yes ^b	inactive
carbonyldiphosphate	yes ^b	inactive
carbamylphosphate	no ^b	nt
phosphonofosphate	yes ^b	inactive
adenosine 5'-diphosphate	yes	inactive
adenosine 5'-triphosphate	yes	inactive
miscellaneous		
rhodizonic acid	yes	high
tetrahydroxy-1,4-quinone	yes	high
ascorbic acid	yes ^b	moderate
hexaketocyclohexane (HKCH)	yes	high
biuret	no ^b	nt
diurea	no ^d	nt
1,2-diacetylhydrazine	no ^b	nt

^a [Fe(III)] = 1.0 mM; 1:1 ligand-Fe molar ratio unless noted otherwise. ^b At 1:1 ligand-Fe molar ratio. ^c nt, not tested. ^d Only slightly soluble. Saturated diurea solution was used.

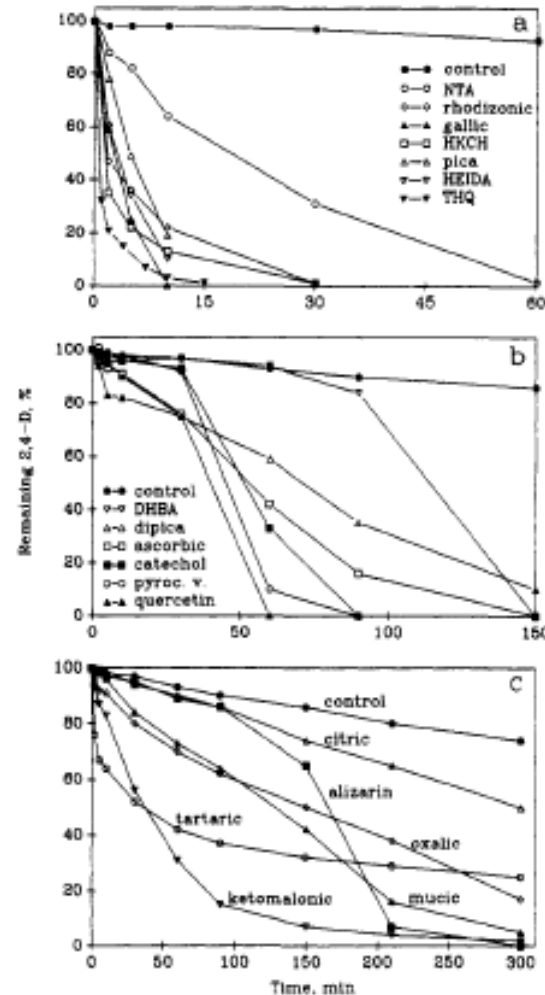


Figure 1. Transformation of 2,4-D by active iron(III) chelates: (a) high, (b) moderate, and (c) low activity. [2,4-D] = 0.1 mM; [chelate] = 1.0 mM; $[H_2O_2]$ = 10 mM; pH 6.0.

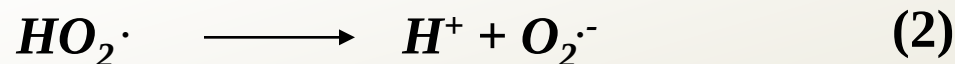
Modified Fenton reaction (Fenton-like Process ; AOPs)

Producing reductant such as

- Superoxide radical anion($O_2^{\cdot-}$)
- Hydroperoxide anion($HO_2^{\cdot-}$)

Desorption

Degradation of chlorinated compounds using dechloronation



Fenton-like reaction (AOPs)

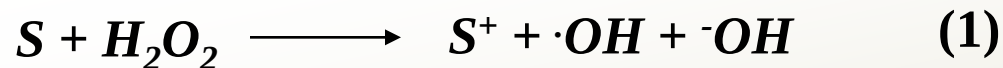
Natural surface soil contain 5% of iron minerals

- Such as **goethite**, **magnetite** and **hematite**
- It could be used instead of ferrous and ferric ions.

The advantage of decreasing iron sludge

Reducing the treatment cost

A possible mechanism for mineral-catalyzed Fenton-Like reaction



S : mineral surface

S⁺: oxidized region on the mineral

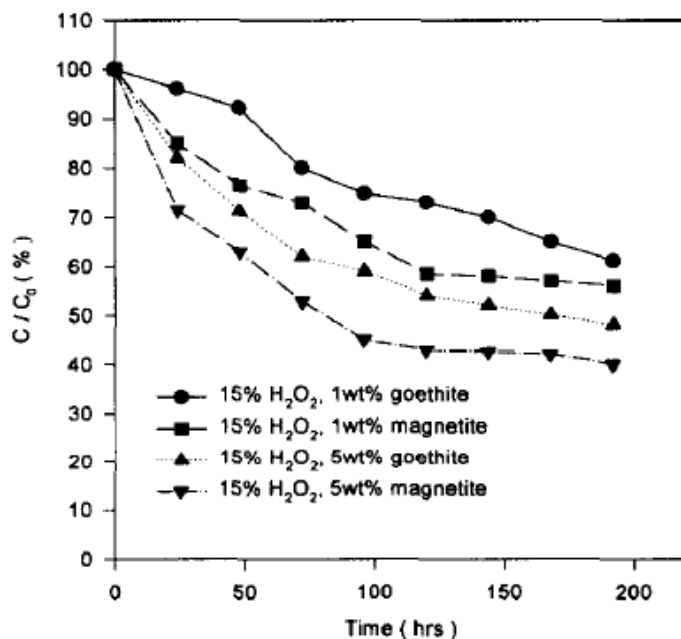
Fenton-like reaction (AOPs)

Fig. Breakdown of mixture of diesel and kerosene at different species and amount of iron minerals with 0.5g contaminant/kg soil and 15% H₂O₂

Table. Generation of soluble iron from magnetite and goethite system treated with 15% H₂O₂ after 5days

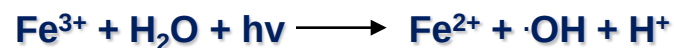
	Magnetite				Goethite			
	1 wt%		5wt%		1 wt%		5wt%	
	pH 2~3	pH 7	pH 2~3	pH 7	pH 2~3	pH 7	pH 2~3	pH 7
Soluble iron concentration (ppm)	6.7	N.D.	8.2	0.7	N.D.	N.D.	N.D.	N.D.
N.D.: not detected								

Sung-ho Kong/*Chemosphere* 1998, 37(8) 1473-1482

Photo-assisted Fenton reaction (AOPs)

Applying ultraviolet (UV) light

Increase reduction of ferric ion to ferrous ion



Furthermore, producing two hydroxyl radicals initiated by UV



Fenton reaction is strongly accelerated by irradiation with UV-VIS light

Potassium permanganate (KMnO₄)

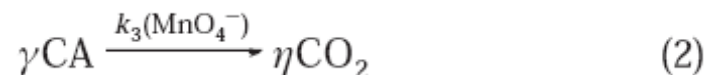
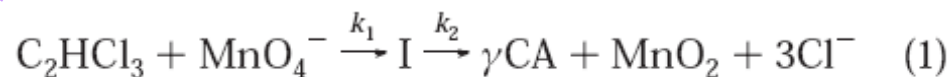
In the in-situ oxidative degradation of chlorinated ethenes with a metal-oxo reagent

Attractive method due to the **rapid degradation of chlorinated ethenes**

The nonreactive nature of the reagent with carbonate and bicarbonate

Low cost

Disadvantage of this method : Color problem



I : Cyclic complex

CA : Various carboxylic acids

γ and η : stoichiometric coefficient

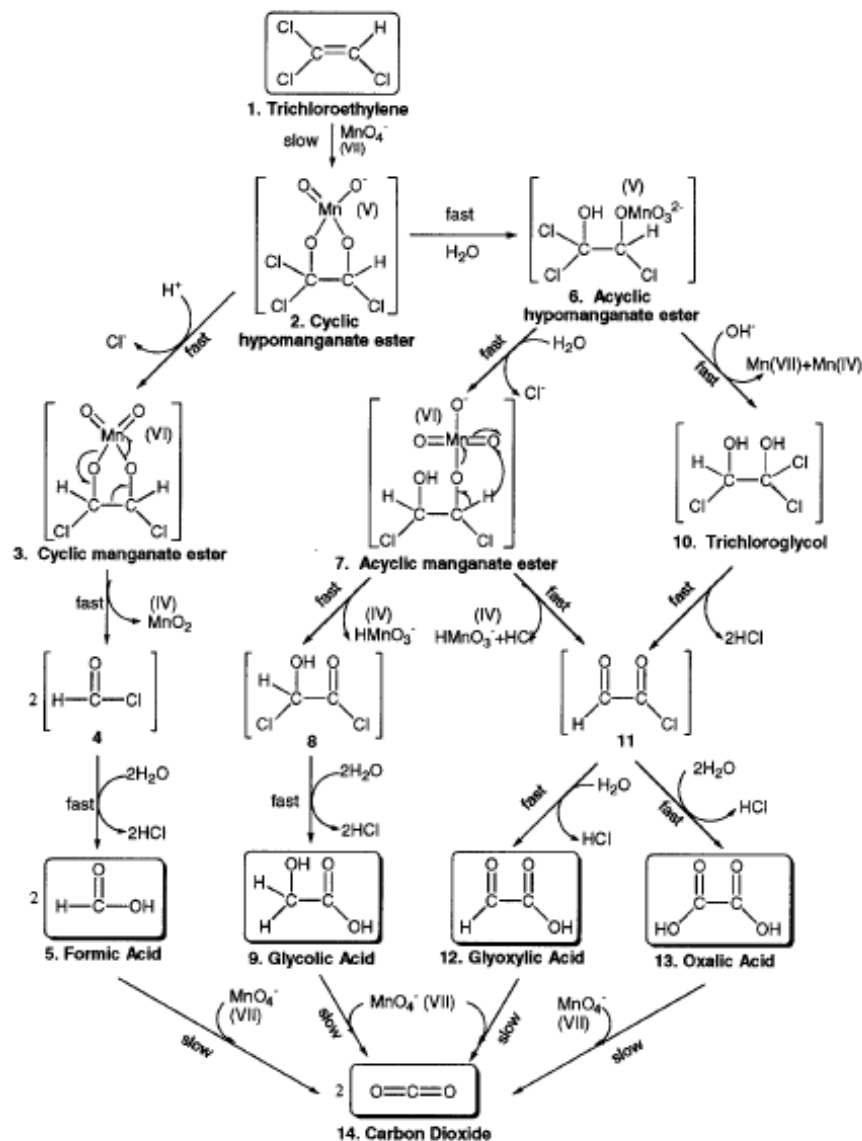
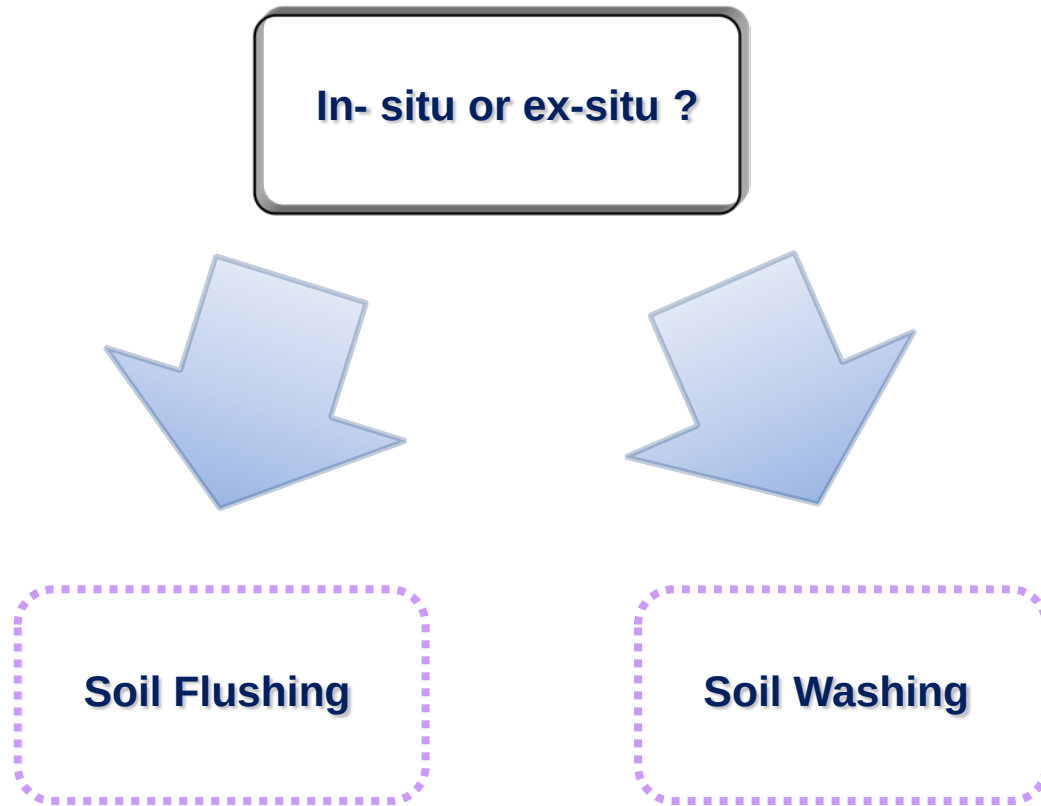


FIGURE 1. Proposed TCE oxidation pathways. Shaded boxes are products identified in this study.

Difference of Soil Washing/Flushing



A treatment technology for removing contaminants from excavated soil

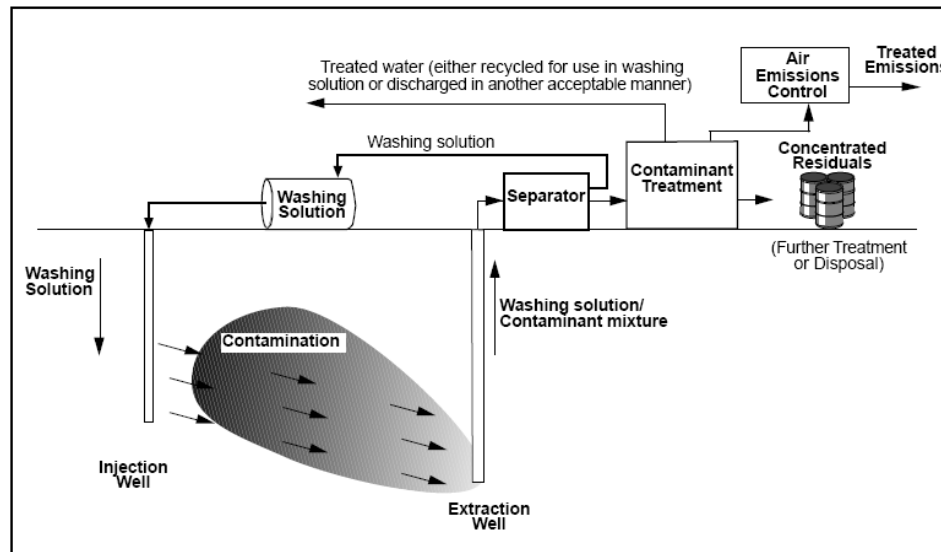
Accomplished by contacting soil with a wash solution, separating the soil



Introduction of Soil Flushing

The extraction of contaminants from in situ soil with water or other suitable aqueous solutions.

Accomplished by passing the extraction fluid through in-place soils using an injection and recovery process.



Soil Flushing Process

Target contaminants

Refractory compounds

- TPH
- Chlorinated compounds
- MTBE
- Etc..

Heavy metals

- Cd
- Cu
- Pb
- Etc..

Washing solution

Water
Surfactant

Water
Acidic solution
Chelating agent solution

Project : Ministry of Environment

Objective of project

- Degradation of heavy metal contaminated soil using organic/inorganic mixed solution
- Development of recirculation system for removing heavy metal for effluent
- Development of Soil Washing system

Project : Ministry of Environment

Soil washing system



Project : Ministry of Environment



Separator



Separator and conveyer

Project : Ministry of Environment

Washing reactor

Mixing reactor

1st Washing reactor

2nd Washing reactor



- Soil vapor extraction (SVE), soil venting or vacuum extraction
 - ✓ In situ remedial technology
 - ✓ Reducing concentrations of volatile constituents in petroleum products adsorbed to soils in the unsaturated (vadose) zone
- In this technology, a vacuum is applied to the soil matrix to create a negative pressure gradient that causes movement of vapors toward extraction wells.
- Volatile constituents (VOC or SVOC) are readily removed from the subsurface through the extraction wells.

Exhibit II-1
Typical SVE System

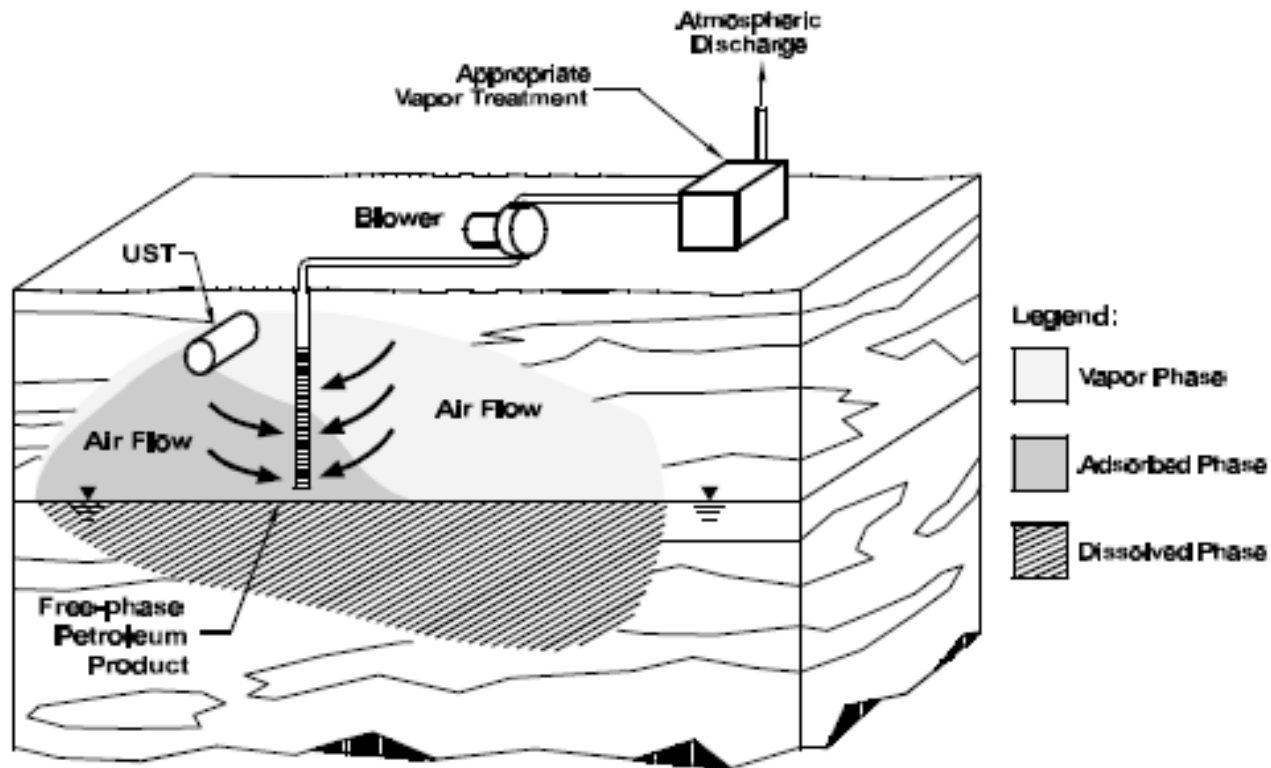


Exhibit II-2 Advantages And Disadvantages Of SVE

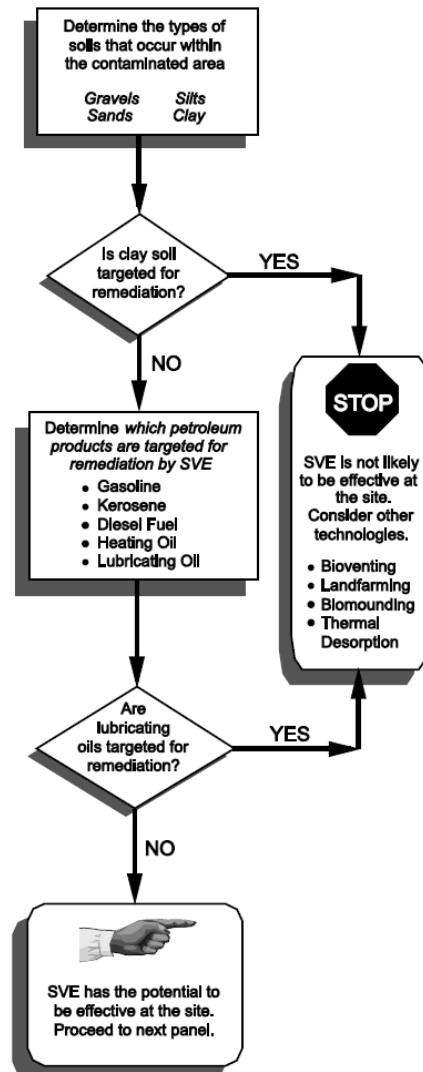
Advantages

- Proven performance; readily available equipment; easy installation.
- Minimal disturbance to site operations.
- Short treatment times: usually 6 months to 2 years under optimal conditions.
- Cost competitive: \$20-50/ton of contaminated soil.
- Easily combined with other technologies (e.g., air sparging, bioremediation, and vacuum-enhanced dual-phase extraction).
- Can be used under buildings and other locations that cannot be excavated.

Disadvantages

- Concentration reductions greater than about 90% are difficult to achieve.
- Effectiveness less certain when applied to sites with low-permeability soil or stratified soils.
- May require costly treatment for atmospheric discharge of extracted vapors.
- Air emission permits generally required.
- Only treats unsaturated-zone soils; other methods may also be needed to treat saturated-zone soils and groundwater.

INITIAL SCREENING OF SVE EFFECTIVENESS



DETAILED EVALUATION OF SVE EFFECTIVENESS

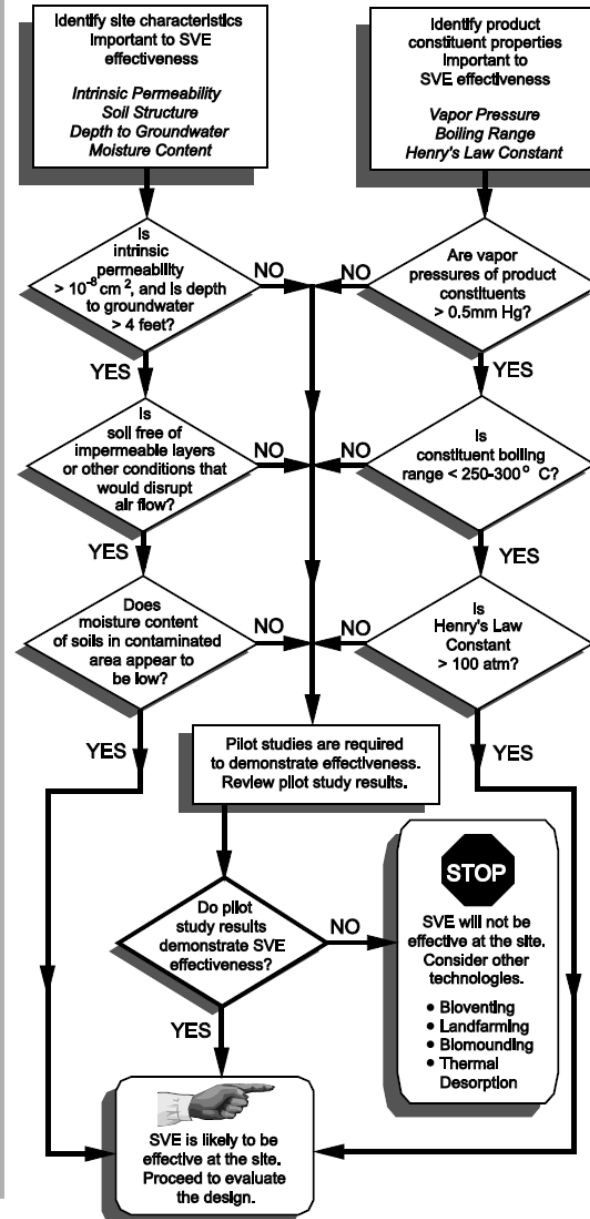


Exhibit II-4
Initial Screening For SVE Effectiveness

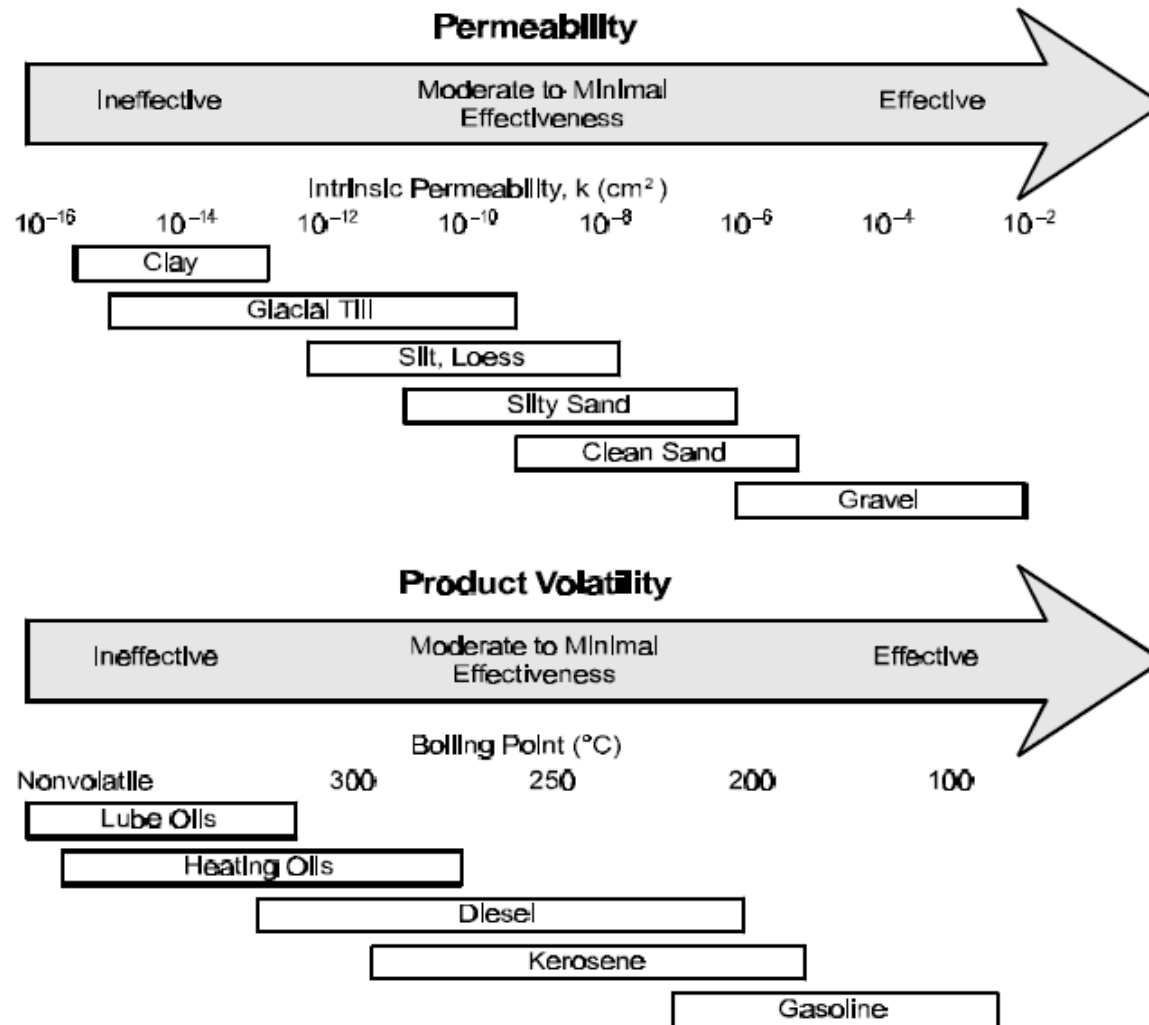


Exhibit II-5 Key Parameters Used To Evaluate Permeability Of Soil And Constituent Volatility

Permeability Of Soil	Constituent Volatility
Intrinsic permeability Soil structure and stratification Depth to groundwater Moisture content	Vapor pressure Product composition and boiling point Henry's law constant

Exhibit II-6 Intrinsic Permeability And SVE Effectiveness

Intrinsic Permeability (k)	SVE Effectiveness
$k \geq 10^{-8} \text{ cm}^2$	Generally effective.
$10^{-8} \geq k \geq 10^{-10} \text{ cm}^2$	May be effective; needs further evaluation.
$k < 10^{-10} \text{ cm}^2$	Marginal effectiveness to ineffective.

Exhibit II-7
Depth To Groundwater And SVE Effectiveness

Depth To Groundwater	SVE Effectiveness
> 10 feet	Effective
3 feet < depth < 10 feet	Need special controls (e.g., horizontal wells or groundwater pumping)
< 3 feet	Not generally effective

Exhibit II-8
Vapor Pressures Of Common Petroleum Constituents

Constituent	Vapor Pressure (mm Hg at 20° C)
Methyl t-butyl ether	245
Benzene	76
Toluene	22
Ethylene dibromide	11
Ethylbenzene	7
Xylenes	6
Naphthalene	0.5
Tetraethyl lead	0.2

Exhibit II-9
Petroleum Product Boiling Point Ranges

Product	Boiling Point Range (°C)
Gasoline	40 to 225
Kerosene	180 to 300
Diesel fuel	200 to 338
Heating oil	>275
Lubricating oils	Nonvolatile

Exhibit II-10
Henry's Law Constant Of Common Petroleum Constituents

Constituent	Henry's Law Constant (atm)
Tetraethyl lead	4700
Ethylbenzene	359
Xylenes	266
Benzene	230
Toluene	217
Naphthalene	72
Ethylene dibromide	34
Methyl t-butyl ether	27

Exhibit II-13
Typical Vertical Soil Vapor Extraction Well Construction

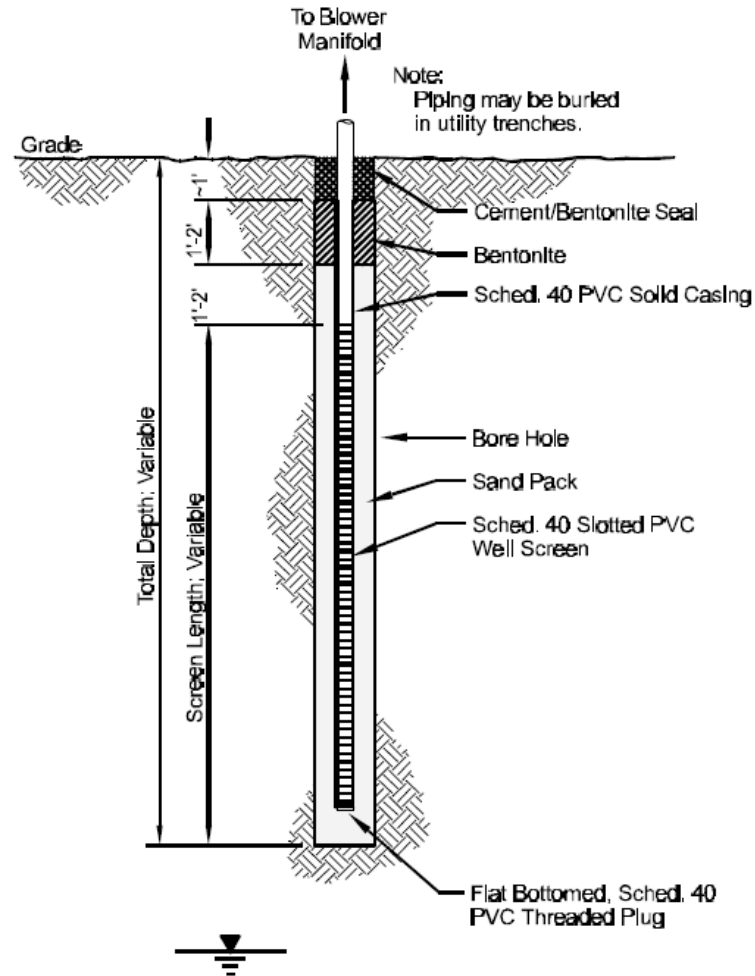
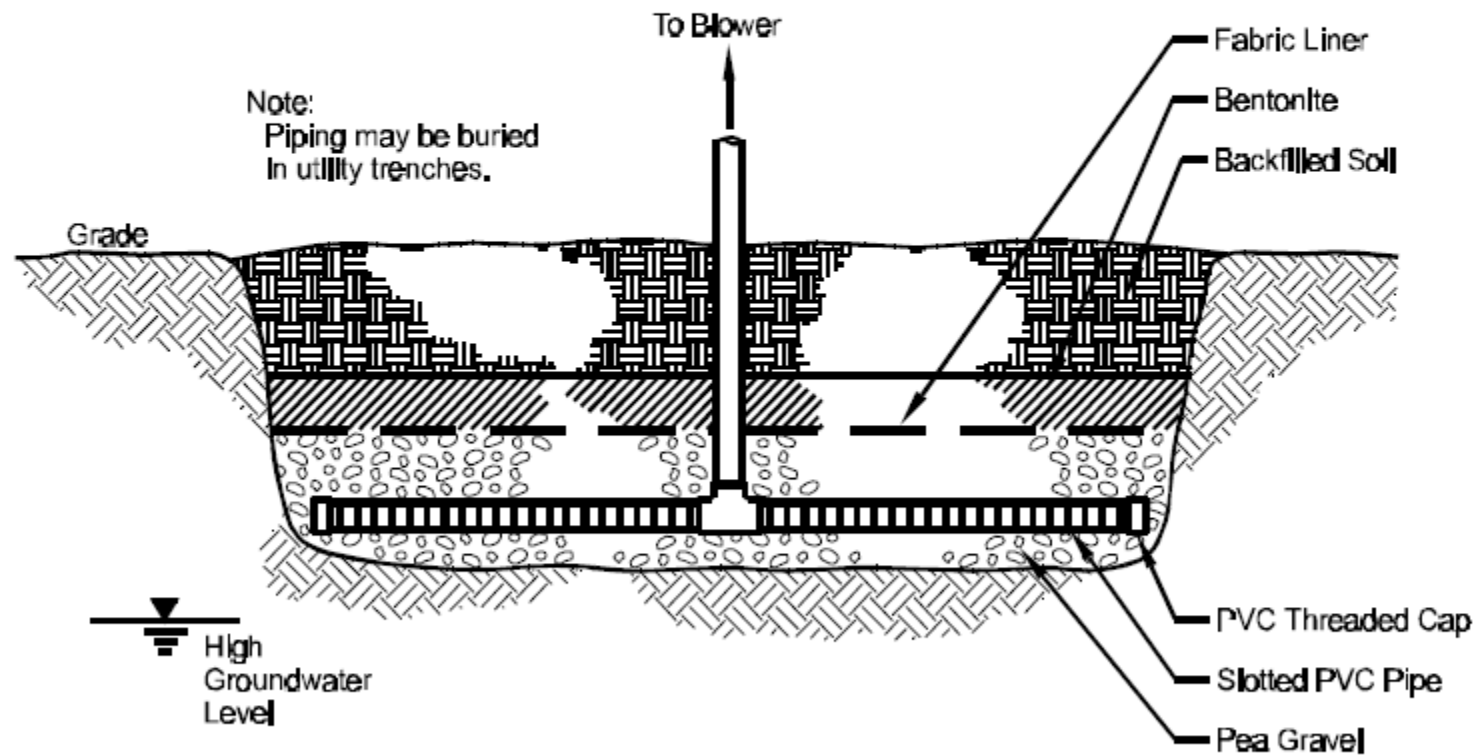


Exhibit II-14 Typical Horizontal Soil Vapor Extraction Well Construction



- Bioventing is an in-situ remediation technology
- Indigenous microorganisms to biodegrade organic constituents adsorbed to soils in the unsaturated zone.
- The activity of the indigenous bacteria is enhanced by inducing air (or oxygen) flow into the unsaturated zone (using extraction or injection wells) and, if necessary, by adding nutrients.
- All aerobically biodegradable constituents can be treated by bioventing.

Exhibit III-1
Typical Bioventing System Using Vapor Extraction

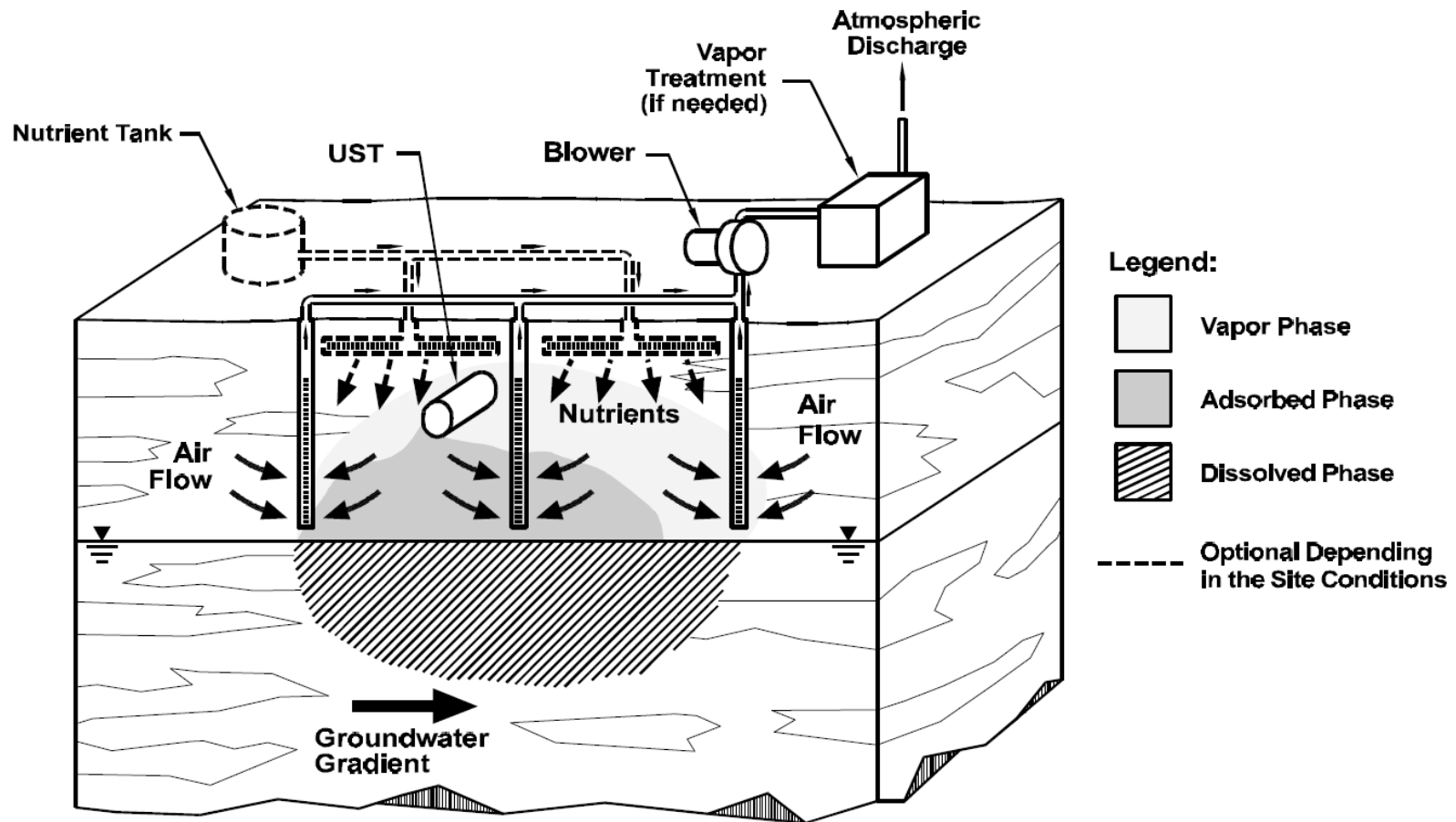


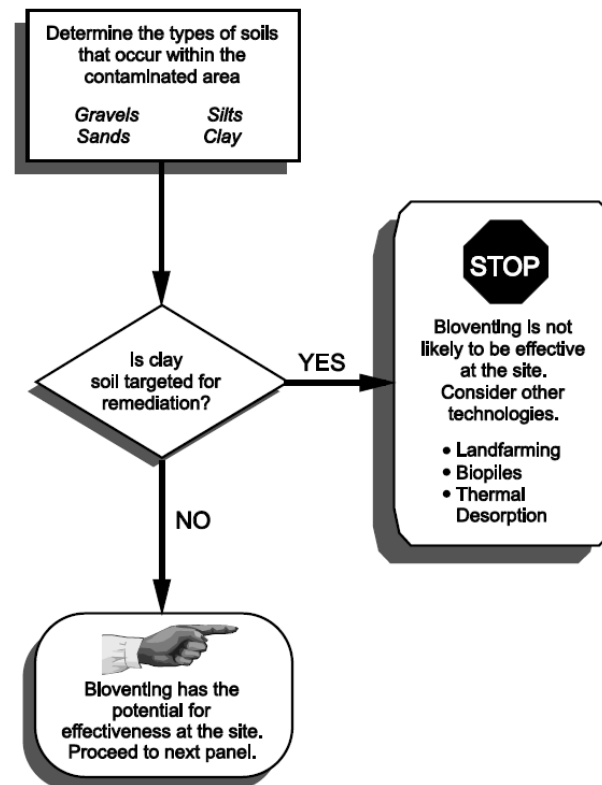
Exhibit III-2 Bioventing Summary

Advantages

- Uses readily available equipment; easy to install.
- Creates minimal disturbance to site operations. Can be used to address inaccessible areas (e.g., under buildings).
- Requires short treatment times: usually 6 months to 2 years under optimal conditions.
- Is cost competitive: \$45-140/ton of contaminated soil.
- Easily combinable with other technologies (e.g., air sparging, groundwater extraction).
- May not require costly offgas treatment.

Disadvantages

- High constituent concentrations may initially be toxic to microorganisms.
- Not applicable for certain site conditions (e.g., low soil permeabilities, high clay content, insufficient delineation of subsurface conditions).
- Cannot always achieve very low cleanup standards.
- Permits generally required for nutrient injection wells (if used). (A few states also require permits for air injection.)



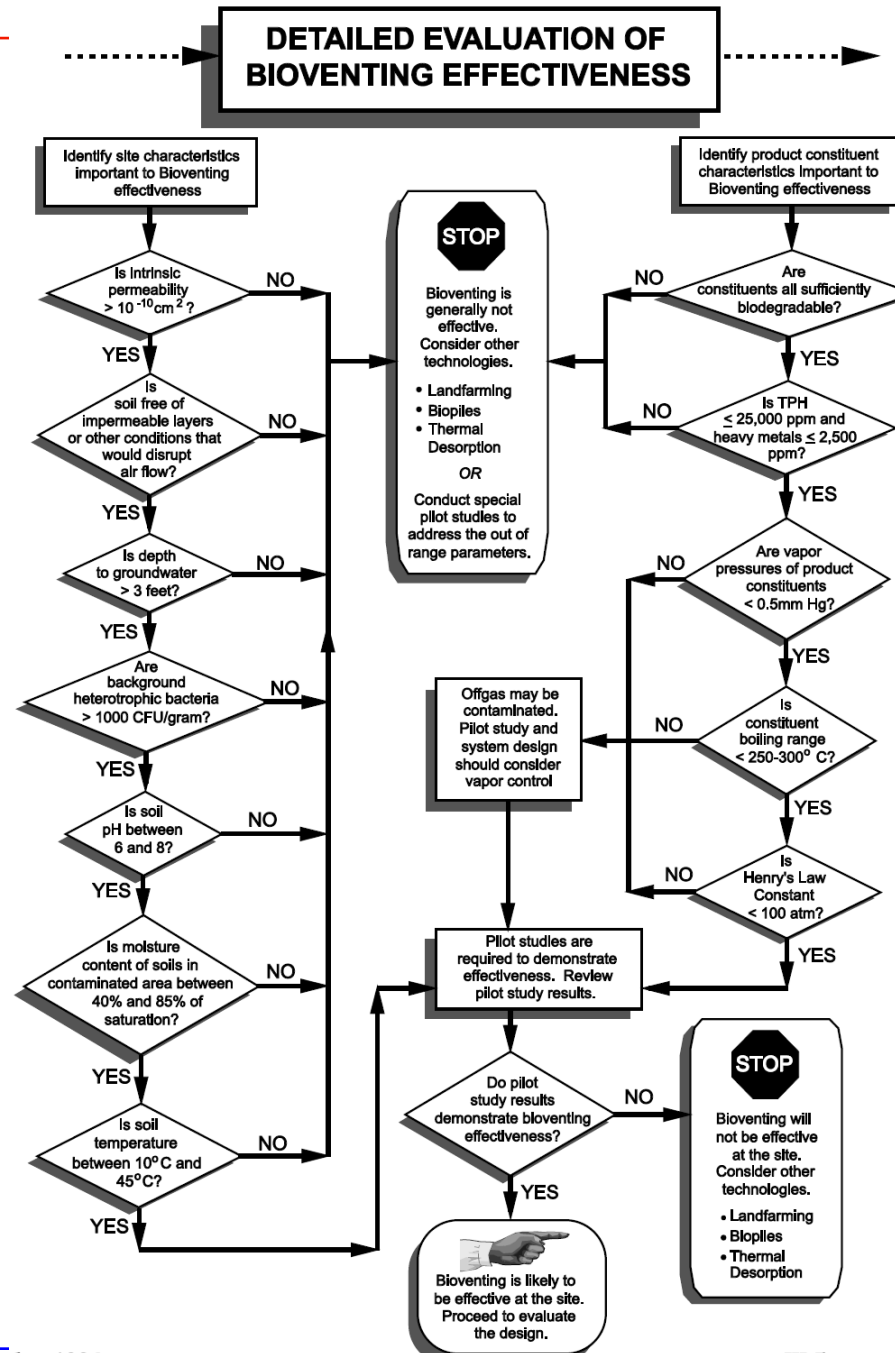
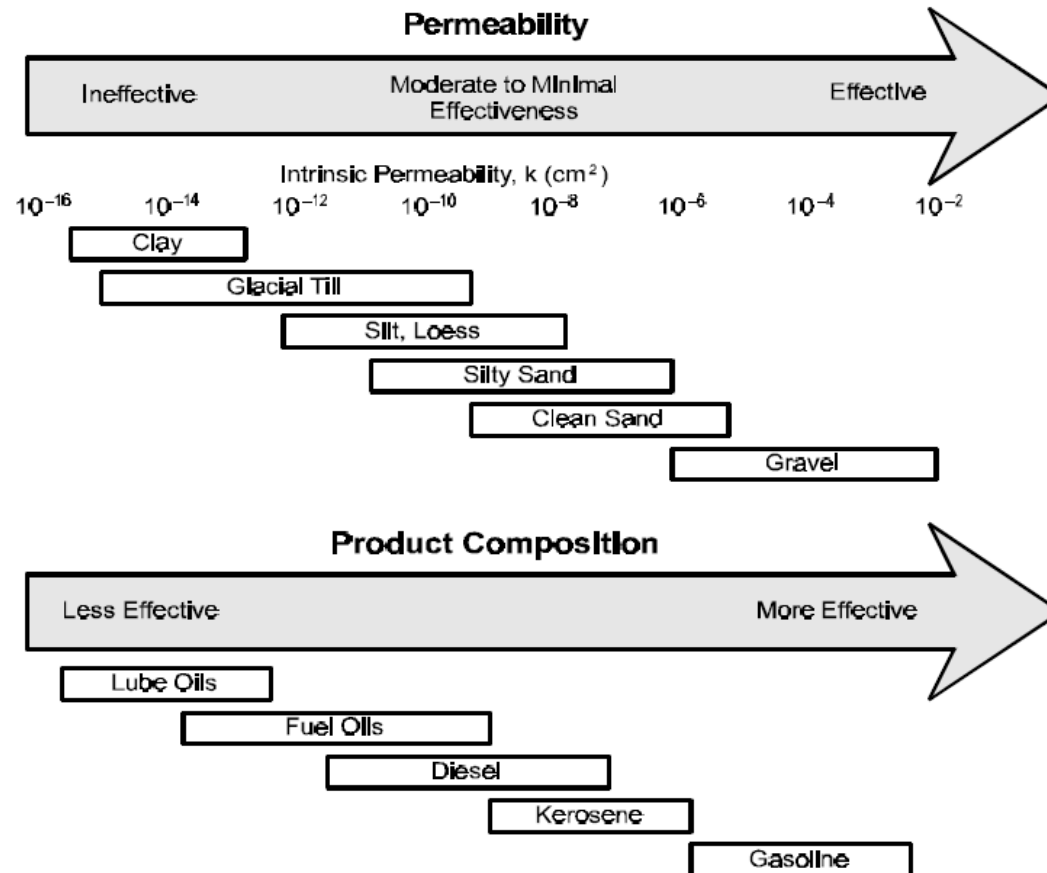


Exhibit III-4 Initial Screening For Bioventing Effectiveness



Note:

All petroleum products listed are amenable for the bioventing remediation alternative.

Exhibit III-5
Key Parameters Used To Evaluate Site Characteristics And
Constituent Characteristics

Site Characteristics

Intrinsic permeability
Soil structure and stratification
Microbial presence
Soil pH
Moisture content
Soil temperature
Nutrient concentrations
Depth to groundwater

Constituent Characteristics

Chemical structure
Concentration and toxicity
Vapor pressure
Product composition and boiling point
Henry's law constant

Exhibit III-7

Intrinsic Permeability And Bioventing Effectiveness

Intrinsic Permeability (cm ²)	Bioventing Effectiveness
$k \geq 10^{-8}$	Effective.
$10^{-8} \geq k \geq 10^{-10}$	May be effective; needs further evaluation.
$k < 10^{-10}$	Not effective.

Exhibit III-8

Heterotrophic Bacteria And Bioventing Effectiveness

Total Heterotrophic Bacteria (prior to bioventing)	Bioventing 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.

Exhibit III-9
Soil pH And Bioventing Effectiveness

Soil pH (prior to bioventing)	Bioventing Effectiveness
$6 \leq \text{pH} \leq 8$	Generally effective.
$6 \geq \text{pH} \geq 8$	Soils will require amendments to correct pH to effective range.

Exhibit III-10
Depth To Groundwater And Bioventing Effectiveness

Depth To Groundwater	Bioventing Effectiveness
> 10 feet	Effective.
3 feet < depth < 10 feet	Need special controls (i.e., horizontal wells or groundwater pumping).
< 3 feet	Not effective.

Exhibit III-11
Chemical Structure And Biodegradability

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

Exhibit III-12
Constituent Concentration And Bioventing Effectiveness

Constituent Concentration

Bioventing Effectiveness

Petroleum constituents $\leq 25,000$ ppm
and
Heavy metals $\leq 2,500$ ppm

Effective.

Petroleum constituents $> 25,000$ ppm
or
Heavy metals $> 2,500$ ppm

Ineffective; toxic or inhibitory conditions to bacterial growth exist. Long remediation times likely.

Exhibit III-13
Cleanup Concentrations And Bioventing Effectiveness

Cleanup Requirement

Bioventing Effectiveness

Constituent concentration > 0.1 ppm
and
TPH reduction $< 95\%$

Effective.

Constituent concentration ≤ 0.1 ppm
or
TPH reduction $\geq 95\%$

Potentially ineffective; pilot studies are required to demonstrate reductions.

- Biopiles, also known as biocells, bioheaps, biomounds, and compost piles
- 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.

Exhibit IV-1
Typical Biopile System

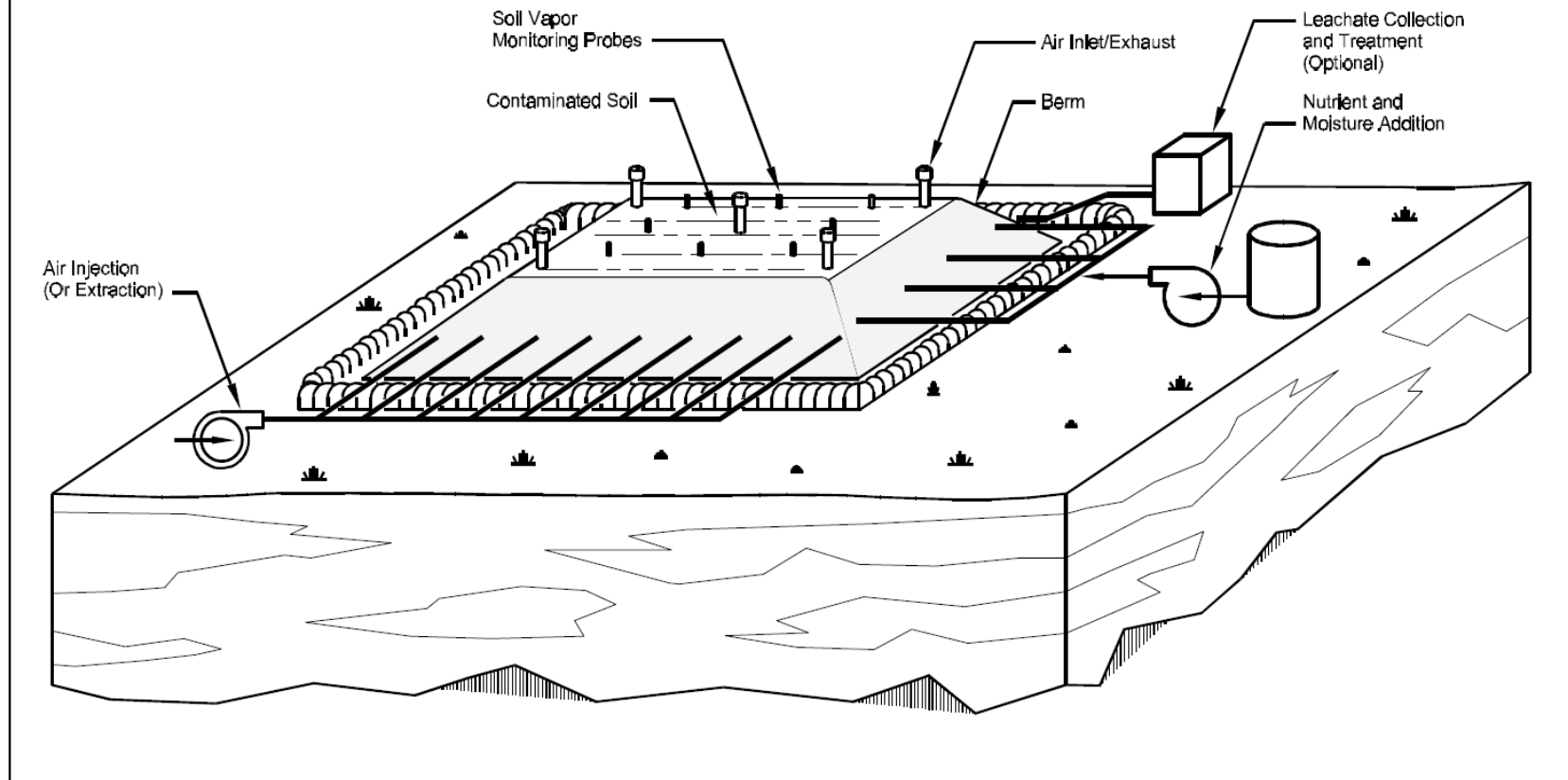


Exhibit IV-2
Advantages And Disadvantages Of Biopiles

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

Exhibit IV-3
Biopile Evaluation Process Flow Chart

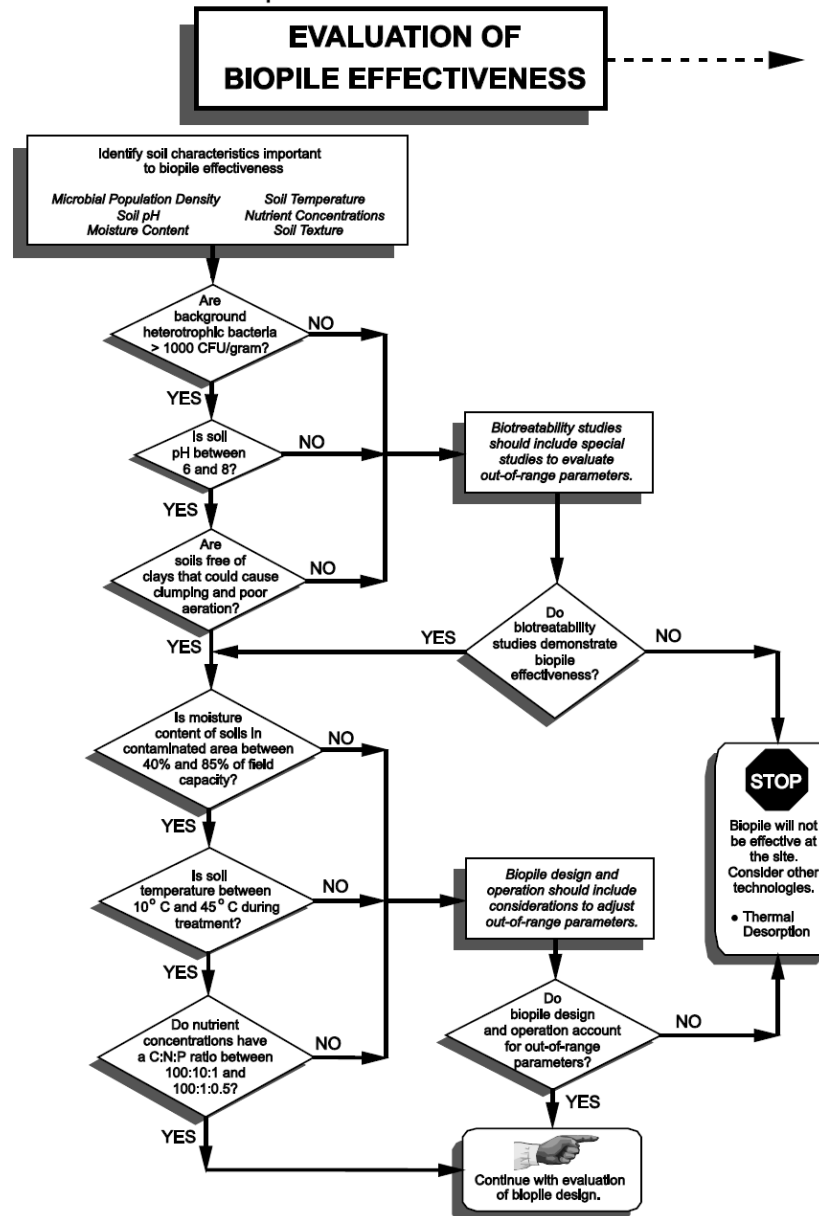


Exhibit IV-3
Biopile Evaluation Process Flow Chart

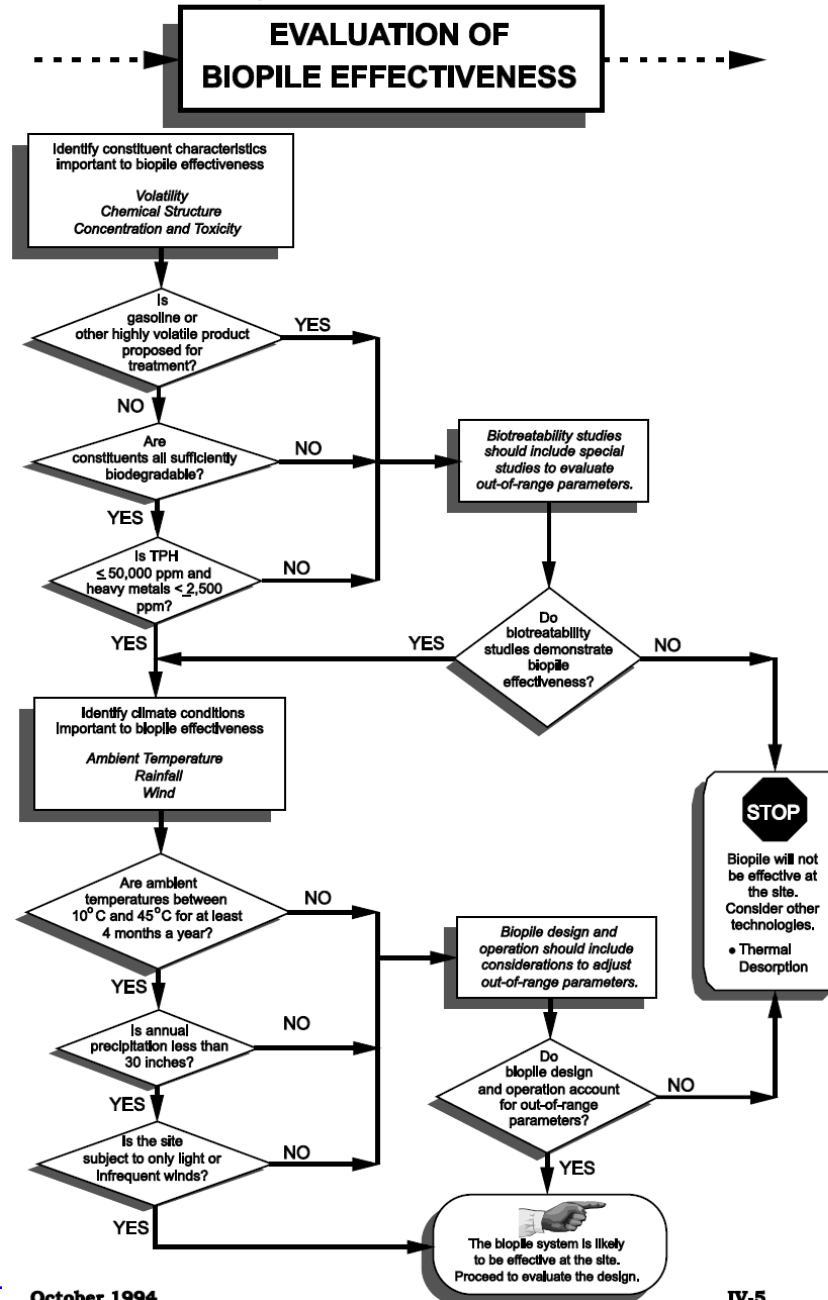


Exhibit IV-4

Parameters Used To Evaluate The Effectiveness Of Biopile Systems

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

Exhibit IV-5

Heterotrophic Bacteria And Biopile Effectiveness

<u>Total Heterotrophic Bacteria (prior to biopile operation)</u>	<u>Biopile Effectiveness</u>
> 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.

Exhibit IV-6 Soil pH And Biopile Effectiveness

Soil pH
(prior to biopile construction)

Biopile Effectiveness

$6 \leq \text{pH} \leq 8$

Generally effective.

$6 > \text{pH} > 8$

Biopile soils will require amendments to correct pH to effective range.

Exhibit IV-7 Soil Moisture And Biopile Effectiveness

Soil Moisture

Biopile Effectiveness

$40\% \leq \text{field capacity} \leq 85\%$

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.

Exhibit IV-8
Soil Temperature And Biopile Effectiveness

Soil Temperature	Biopile Effectiveness
$10^{\circ}\text{C} \leq \text{soil temperature} \leq 45^{\circ}\text{C}$	Effective.
$10^{\circ}\text{C} > \text{soil temperature} > 45^{\circ}\text{C}$	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.

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 Nonane	☐ Gasoline ☐ Diesel fuel
	Methyl butane, dimethylpentenes, methyloctanes	☐ Gasoline
	Benzene, toluene, ethylbenzene, xylenes Propylbenzenes	☐ Gasoline ☐ Diesel, kerosene
	Decanes Dodecanes Tridecanes Tetradecanes	☐ Diesel ☐ Kerosene ☐ Heating fuels ☐ Lubricating oils
	Naphthalenes Fluoranthenes Pyrenes Acenaphthenes	☐ Diesel ☐ Kerosene ☐ Heating oil ☐ Lubricating oils
Less degradable		

Exhibit IV-10
Constituent Concentration And Biopile Effectiveness

Constituent Concentration	Biopile Effectiveness
Petroleum constituents $\leq 50,000$ ppm and Heavy metals $\leq 2,500$ 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.

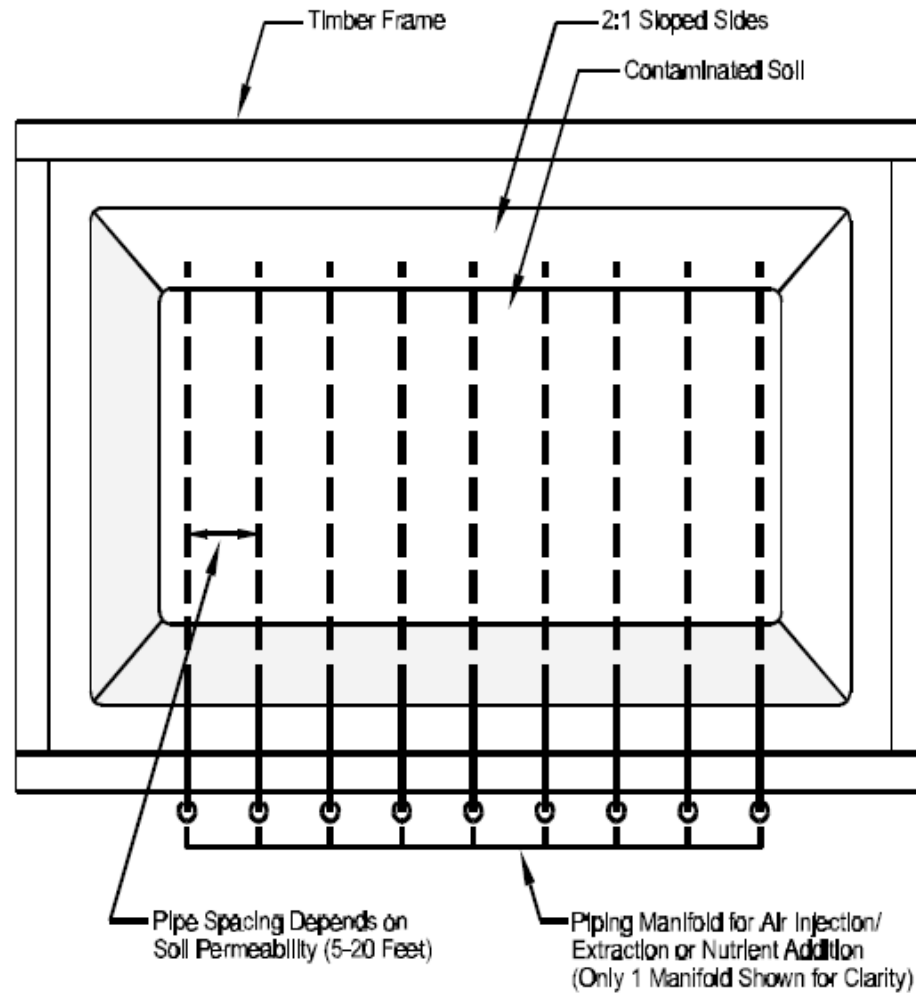
Exhibit IV-11
Cleanup Requirements And Biopile Effectiveness

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

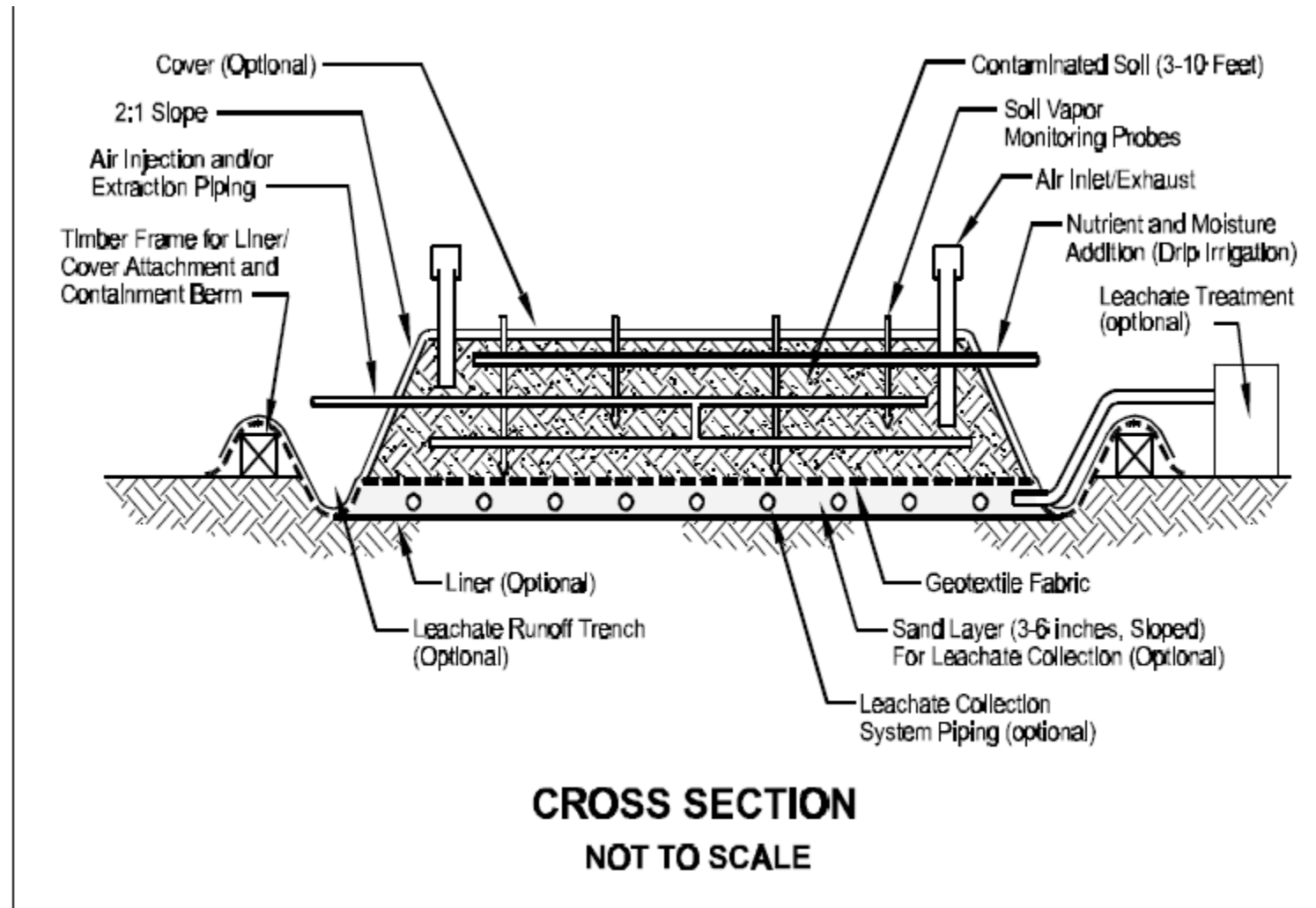
Exhibit IV-12
Physical And Chemical Parameters For Biotreatability Studies

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.

Exhibit IV-13
Construction Design Of A Typical Biopile



PLAN VIEW



- Landfarming, also known as land treatment or land application
 - ✓ An above-ground remediation technology for soils
 - ✓ Reducing 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.

Exhibit V-1
Typical Landfarming Operation

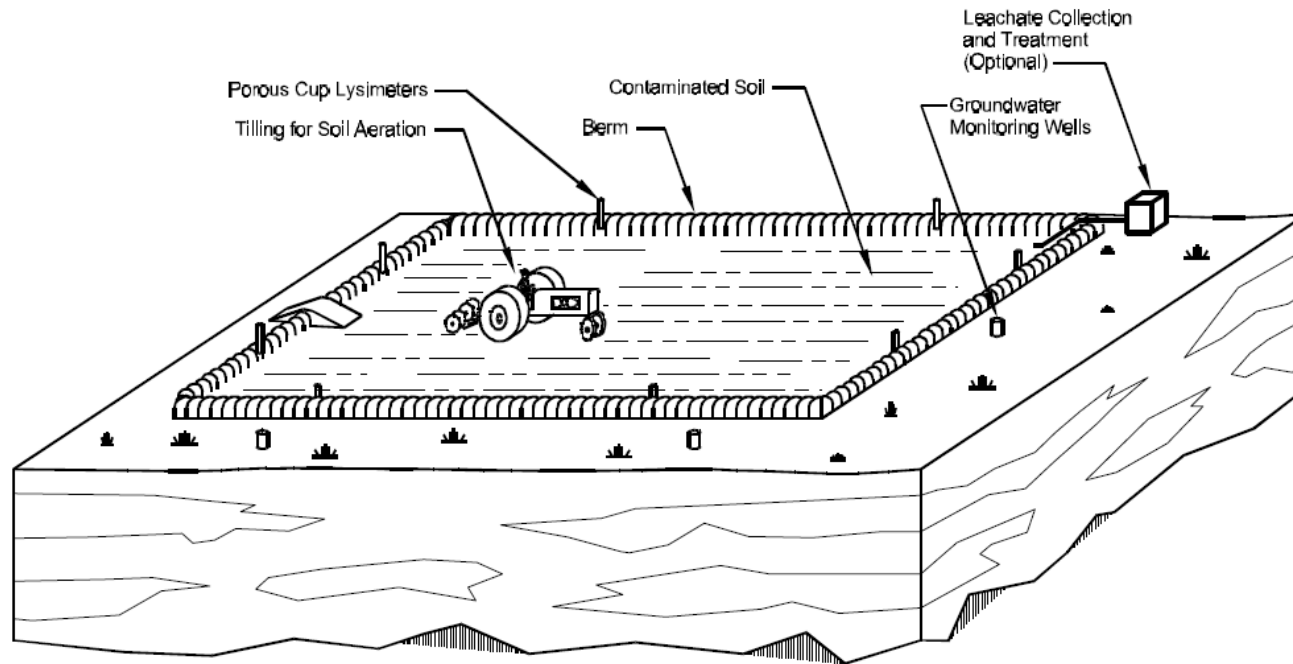


Exhibit V-2
Advantages And Disadvantages Of Landfarming

Advantages

- Relatively simple to design and implement.
- Short treatment times: usually 6 months to 2 years under optimal conditions.
- Cost competitive: \$30-60/ton of contaminated soil.
- Effective on organic constituents with slow biodegradation rates.

Disadvantages

- Concentration reductions > 95% and constituent concentrations < 0.1 ppm are very difficult to achieve.
- May not be effective for high constituent concentrations (> 50,000 ppm total petroleum hydrocarbons).
- Presence of significant heavy metal concentrations (> 2,500 ppm) may inhibit microbial growth.
- 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.

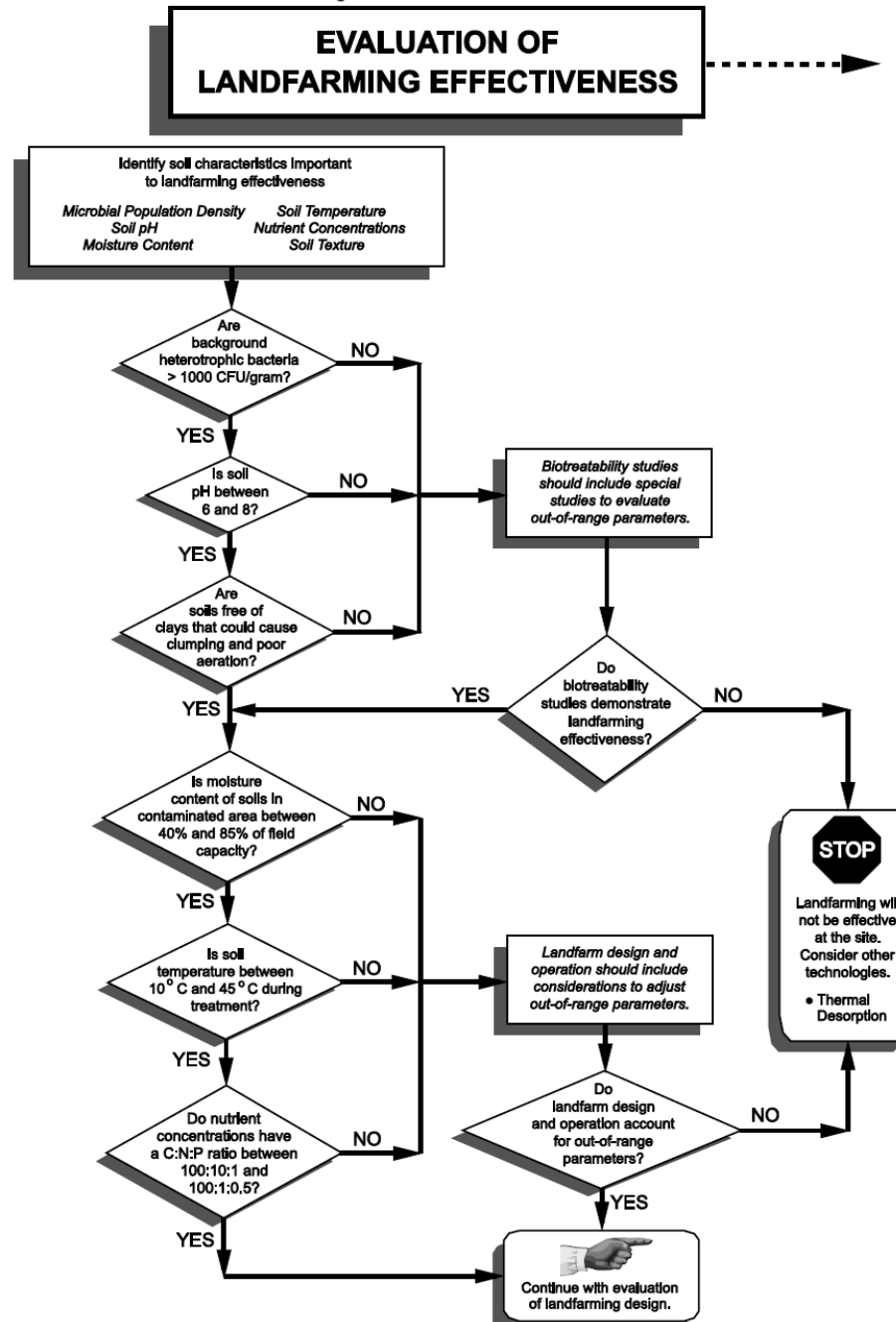


Exhibit V-4
Parameters Used To Evaluate The Effectiveness Of Landfarming

<u>Soil Characteristics</u>	<u>Constituent Characteristics</u>	<u>Climatic Conditions</u>
Microbial population density Soil pH Moisture content Soil temperature Nutrient concentrations Texture	Volatility Chemical structure Concentration and toxicity	Ambient temperature Rainfall Wind

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.

Exhibit V-6
Soil pH And Landfarming Effectiveness

Soil pH
(prior to landfarming)

Landfarming Effectiveness

$6 \leq \text{pH} \leq 8$

Generally effective.

$6 > \text{pH} > 8$

Landfarm soils will require amendments to correct pH to effective range.

Exhibit V-7
Soil Moisture And Landfarming Effectiveness

Soil Moisture	Landfarming Effectiveness
$40\% \leq \text{field capacity} \leq 85\%$	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.

Exhibit V-8
Soil Temperature And Landfarming Effectiveness

Soil Temperature	Landfarming Effectiveness
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Less degradable	Naphthalenes Fluoranthenes Pyrenes Acenaphthenes	○ Diesel ○ Kerosene ○ Heating oil ○ Lubricating oils



Exhibit V-10
Constituent Concentration And Landfarming Effectiveness

Constituent Concentration	Landfarming Effectiveness
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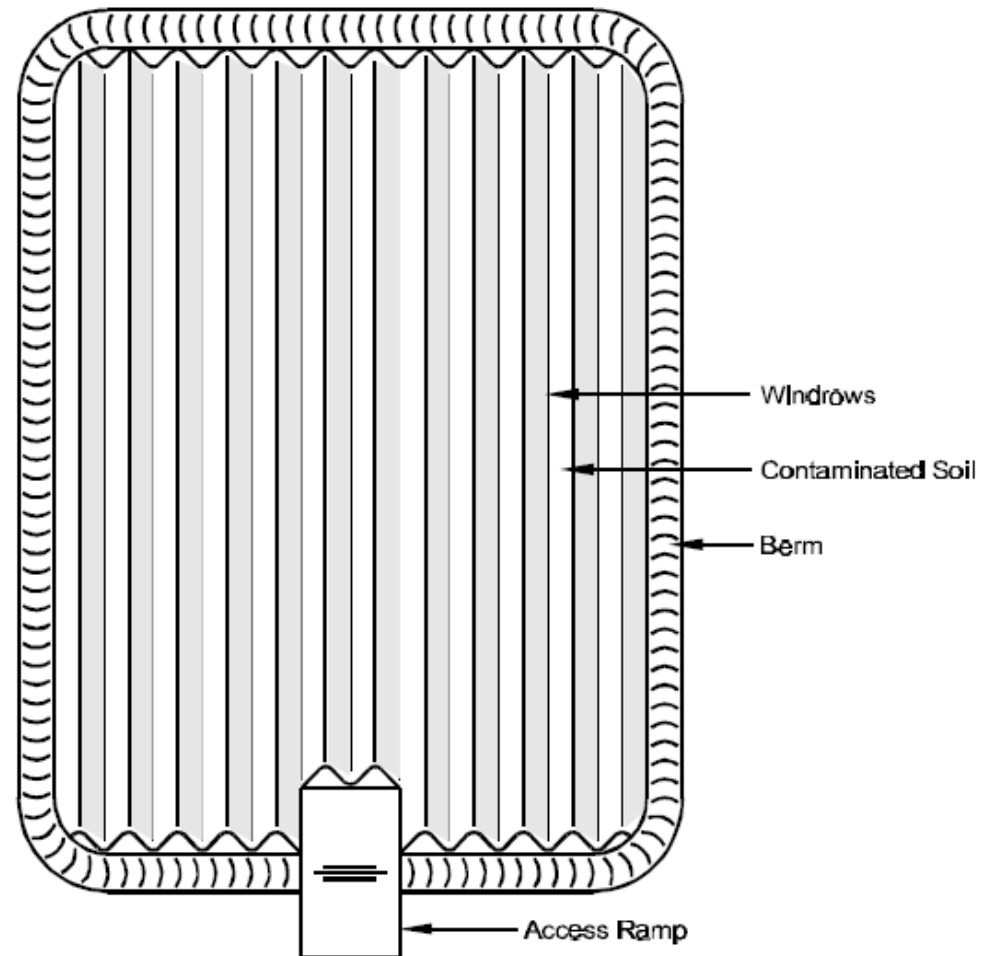
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Cleanup Requirement	Landfarming Effectiveness
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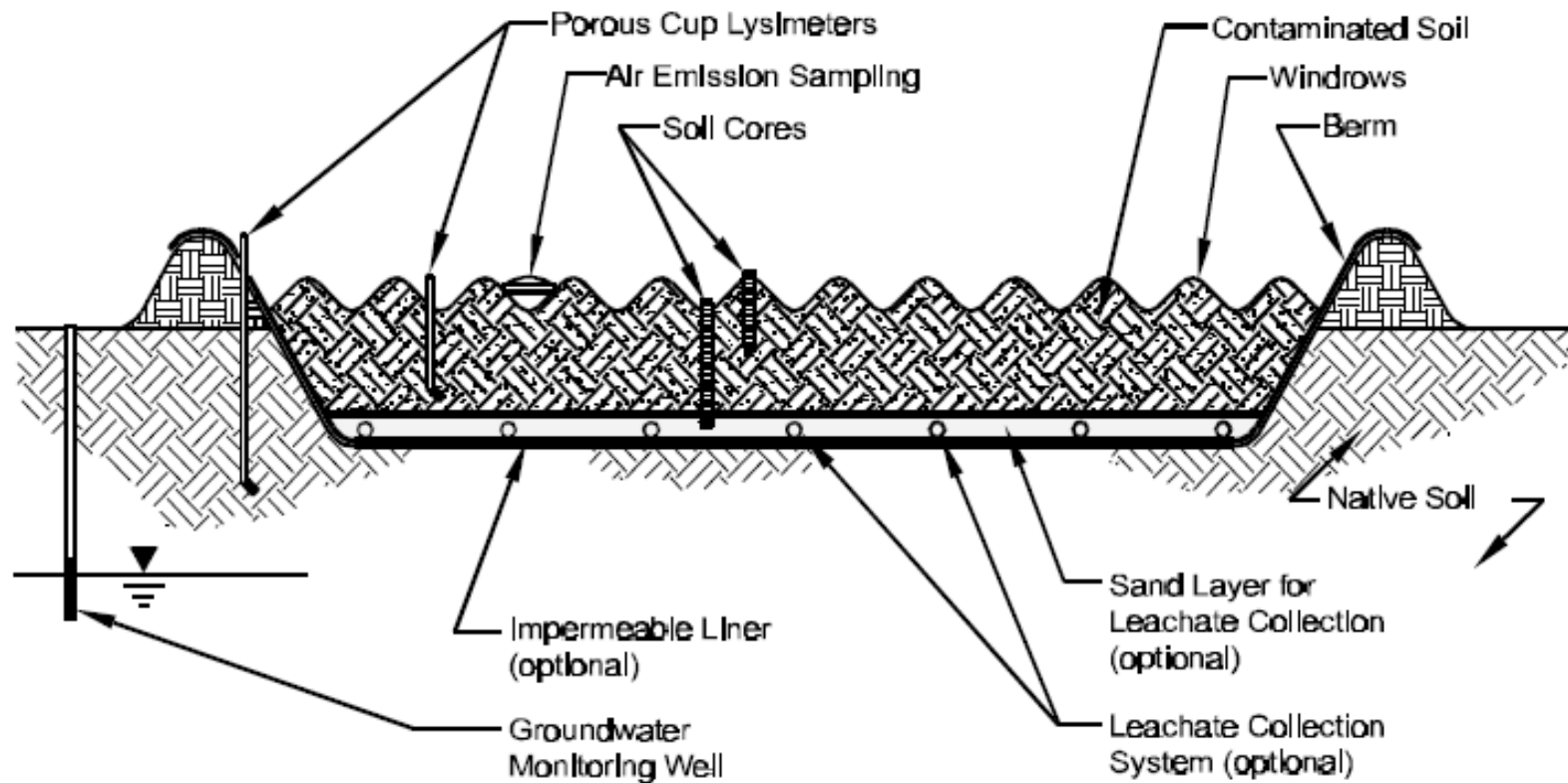
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Nutrients	Nitrate, phosphate, other anions and cations.
Contaminant biodegradability	Total organic carbon concentration, volatility, chemical structure.

Exhibit V-13
Construction Design Of A Typical Landfarm



PLAN VIEW



CROSS SECTION

Thank you !!!