United States
Environmental Protection
Agency

Solid Waste and
Emergency Response
Washington, DC 20460

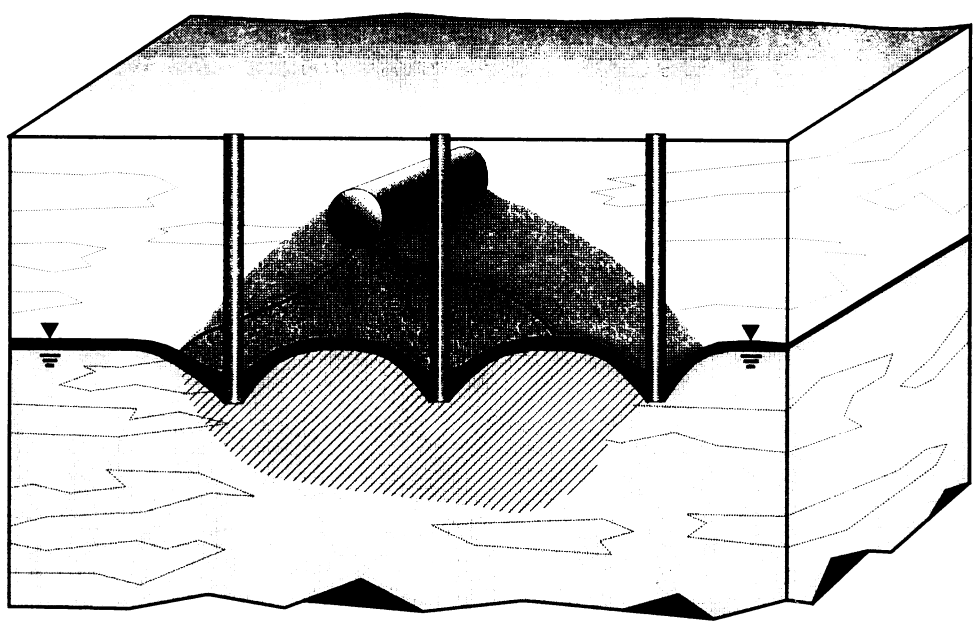
National Risk
Management Research
Laboratory
Cincinnati, OH 45268

EPA 510-R-96-001
September 1996

EPA

How To Effectively Recover Free Product At Leaking Underground Storage Tank Sites

A Guide For State Regulators



How To Effectively Recover Free Product At Leaking Underground Storage Tank Sites

A Guide For State Regulators

United States Environmental Protection Agency
Office of Underground Storage Tanks, OSWER
National Risk Management Research Laboratory, ORD

September 1996

Acknowledgments

This guidance manual is the result of a cooperative effort between the Environmental Protection Agency's (EPA's) Office of Underground Storage Tanks (OUST) and Office of Research and Development, National Risk Management Research Laboratory (NRMRL). OUST would like to express its sincere gratitude to Evan Fan (NRMRL) for his technical assistance and to Tony Tafuri (NRMRL) for his generous contributions in forming this partnership. The principal authors of the document, Charles R. Faust and Michael P. Montroy (both from GeoTrans, Inc.), deserve special recognition for their technical expertise, responsiveness, and commitment to producing this manual. This document underwent extensive peer review by a group of experts drawn from EPA Headquarters, regional offices and laboratories, as well as state regulatory agencies, universities, and private industry. Primary contributors to the technical review process include George Mickelson (Wisconsin Department of Natural Resources), Steve Acree (EPA Robert S. Kerr Environmental Research Laboratory), Harley Hopkins (American Petroleum Institute), Duane Hampton (Western Michigan University), Gary Robbins (University of Connecticut), Jack Hwang (EPA Region 3), Delonda Alexander (Texas Natural Resources Conservation Commission), and Lisa Lund, Dana Tulis and Debby Tremblay (all three from OUST). Other individuals who provided valuable comments for improvement of the manual include Jane Cramer (New Mexico Environment Department), Sandy Stavnes (EPA Region 8), Katrina Varner (EPA Environmental Monitoring and Systems Laboratory), James Atchley (Arkansas Department of Pollution Control and Environment), and Dwayne Conrad (Texaco Research and Development). Special thanks are also due to OUST's outreach team members Lela Hagan-Bijou and Kate Becker.

Hal White, P.G.
OUST, OSWER
September 1996

CONTENTS

CONTENTS
(continued)

CONTENTS
(continued)

EXHIBITS

EXHIBITS
(continued)

CHAPTER I

INTRODUCTION

CHAPTER I

INTRODUCTION

Background

Over 315,000 releases from leaking underground storage tanks (USTs) were reported by state and local environmental agencies as of March 1996[1]. EPA's Office of Underground Storage Tanks (OUST) anticipates that at least 100,000 additional releases will be confirmed in the next few years as tank owners and operators comply with the December 22, 1998, deadline for upgrading, replacing, or closing substandard USTs. Each release represents a potential threat to human health and the environment; appropriate remedial steps must be taken to assess the risk and minimize the impact. The Federal regulations (40 CFR 280.64) state that at UST sites where investigations indicate the presence of free product, owners and operators must remove free product to the maximum extent practicable as determined by the implementing agency. Typically, the implementing agency is represented by the state environmental agency or local fire prevention office. Where the threat is imminent (*e.g.*, seepage of free product into basements or parking garages) an appropriate reponse would be immediate emergency action to prevent explosion or fire. Even where the consequences of the release are not immediately hazardous (*e.g.*, contamination of groundwater resources) expeditious recovery of free product will contribute to minimizing the costs and time required for effective corrective action.

The decision-making process for determining the most appropriate corrective action is intended to develop a remedy to mitigate risks. Typically, the remedial approach is described in a corrective action plan (CAP) or other report along with target clean-up levels to be achieved in an appropriate period of time. The corrective action specified in the CAP may include a combination of alternative techniques (*e.g.,* bioremediation, soil vapor extraction [SVE]), traditional remedial methods (*e.g.,* free product recovery, excavation, pump-and-treat), institutional controls (*e.g.*, deed restrictions), and natural attenuation. At most sites where significant volumes of petroleum have reached the water table, free product recovery is the first step of the remedial approach. Because free product recovery may be initiated prior to implementing long-term corrective action using alternative or traditional technologies, this critical step may not be included in a CAP. The written strategy for recovering free product may

[1]EPA O.U.S.T. Semi-Annual, FY96 UST Activity Report

be presented in a variety of different formats; this guide will refer to such a document as a free product recovery plan.

Releases of petroleum products may occur above ground (*e.g*., spills, leaks from exposed piping) or below ground (*e.g*., leaks from tanks or piping). Recovery of product above the ground is relatively routine, and effective methods for cleaning up these releases from the ground surface, surface water bodies, or sewers and other underground conduits are well established. Recovery of product from below the ground is usually much more difficult, more costly, and less effective. Released product first soaks into the soil, and only if the volume of release is large enough will free product accumulate at the water table. The soil will retain a significant portion of the product, but as this portion is immobile, it does not contribute to that portion termed “free product”.

This manual addresses recovery of free product below the ground surface. A few standard technologies are typically used to recover free product under these conditions. These methods include the following:

- Simultaneous withdrawal of vapor (air and vapor phase hydrocarbons) and fluids (groundwater and free product).

- Collection of free product using skimming equipment in wells, trenches, or excavations.

- Pumping of free product by depressing the water table to enhance migration of free product to a well or drain.

The design of any of the above remedial systems requires an understanding of the site hydrogeological conditions and characteristics, the types, extent, and distribution of free product in the subsurface, and the engineering aspects of the equipment and installations.

Purpose

The purpose of this manual is to provide you–-state and local regulators–-with guidance that will help you review strategies for recovery of free product from beneath the ground surface. The manual does not advocate the use of one technology over another; rather it focuses on appropriate technology use, taking into consideration site-specific conditions.

The manual is designed to enable you to answer the following three basic questions when reviewing a free product recovery plan.

- Is recovery of the free product necessary?
- Has an appropriate method been proposed for recovering the free product?
- Does the free product recovery plan provide a technically sound approach to remediating the site?

Scope And Limitations

This manual is intended to provide technical guidance to state and local regulators who oversee cleanups and evaluate free product recovery plans at petroleum release sites. It does not represent the issuance of formal policy or in any way affect the interpretation of the regulations.

The text focuses on scientific and engineering-related considerations for evaluating various technologies for the recovery of free product from the subsurface. It does not provide instruction on the design and construction of remedial systems and should not be used for designing free product recovery plans. In addition, this manual should not be used to provide guidance on regulatory issues, such as securing permits and establishing cleanup standards, health and safety issues, state-specific requirements, or cleanup costs.

This document is not intended to be used as the sole reference for review of free product recovery plans. Rather, it is intended to be used along with published general references (*e.g.*, EPA, 1995; Newell *et al.*, 1995; API, 1989, 1996; and ASTM, 1995), guidance from technical experts, information from training courses, and current journals.

The material presented is based on available technical data and information and the knowledge and experience of the authors and peer reviewers.

How to Use This Manual

EPA's OUST encourages you to use this manual at your desk as you review free product recovery plans. We have designed the manual so that you can tailor it to meet your state's or your own needs. The three-ring binder allows you to insert additional material (*e.g.*, state-specific guidance on permitting and technology relevant to free product recovery) and remove certain tools (*e.g.*, flow charts, checklists) for photocopying.

The wide margins in this manual were provided to enable you to add your own notes to the text.

The manual contains the following four chapters that address the major considerations necessary for reviewing plans for recovering free product.

Chapter II	*The Corrective Action Process* is an overview of free product recovery actions. This chapter contains information that is used in determining the complete remedial action or interim action, the remedial objectives, and the technology evaluation process.
Chapter III	*Behavior of Hydrocarbons in the Subsurface* is an overview of important properties of hydrocarbons and geologic media that must be considered when designing a free product recovery system.
Chapter IV	*Methods for Evaluating Recoverability of Subsurface Hydrocarbons*. This chapter contains discussions of the methods used both to characterize the extent of free product at a site as well as to estimate the volume of free product at the water table and the rates at which it can be recovered.
Chapter V	*Hydrocarbon Recovery Systems/Equipment*. This chapter contains descriptions of alternative recovery technologies and it addresses applicability, system design, and monitoring requirements.

As appropriate, the discussion in each chapter has illustrations, comparative tables, example calculations, flow charts, and a list of selected key references. An appendix, a glossary of relevant terms, and a comprehensive list of references appear at the end of the manual.

At the back of the manual, a step-by-step checklist is provided to facilitate your review of a proposed free product recovery system. This checklist can help you determine whether or not the free product recovery plan contains the necessary supporting information to approve the free product recovery system. The checklist is also designed to verify that an appropriate technology and design have been selected for free product recovery.

CHAPTER II

THE CORRECTIVE ACTION PROCESS

CHAPTER II

THE CORRECTIVE ACTION PROCESS

Releases from underground storage tanks and piping caused by leaks, spills, or overfills may result in a subsurface accumulation of a separate phase liquid ("free product" or "free phase") that will flow into wells or excavations. Other terms that are sometimes used to refer to free product include; phase separated hydrocarbons (PSH), liquid hydrocarbons (LHC), liquid phase hydrocarbons (LPH), and nonaqueous phase liquids (NAPL). These alternative terms also refer to separate phase liquids in the subsurface that are not present in an amount sufficient for them to flow readily into wells or excavations. In this situation, the petroleum hydrocarbons represent a separate residual phase, but not a "free product" phase.

Confirmation of a release from an underground storage tank (UST) and/or its associated piping initiates the corrective action process. At sites where free product is present in the subsurface, free product recovery will be part of most corrective actions, although it may precede development of a formal corrective action plan (CAP). Before addressing the corrective action process, a brief overview of hydrocarbon releases to the subsurface is presented.

Hydrocarbon Releases To The Subsurface

The release of hydrocarbons from an UST can occur under a wide range of operational conditions and environmental settings. The extent of any threat to human health and the environment will depend on these release-specific conditions. Factors that significantly determine the level of risk include the following:

- Type of petroleum hydrocarbon(s) and the contaminants of concern.

- Volume and age of the release.

- Contaminant migration pathways (*e.g.*, utility trenches, sewers, drinking water supplies) to reach receptors.

- Proximity of receptors to the site of the release. Receptors include human and animal populations, as well as environmental receptors (*e.g.,* groundwater resources, surface waters, buildings, residences).

- Receptor exposure pathways (*e.g.*, ingestion of water or soil, inhalation of vapors).

The hydrocarbons associated with UST releases are usually fuels, oils, or lubricants and almost all are less dense than water, therefore they float on top of the water table. Liquid phase hydrocarbons (residual and free) that are less dense than water are also referred to by the acronym LNAPL (light nonaqueous phase liquids). A nonaqueous phase liquid that is more dense than water is called DNAPL (dense nonaqueous phase liquid). DNAPLs sink throughout the saturated zone to accumulate at the bottom of the aquifer where their movement is dictated by gravity and the topography of the subsurface geologic layers. Solvents such as trichloroethylene and other chlorinated hydrocarbons are DNAPLs. Some of the non-hydrocarbon fuel additives (*e.g.*, MTBE, ethanol) are extremely soluble and dissolve into, and can be transported over long distances by, flowing groundwater.

The volume and the age of the release are the factors that largely control the potential extent of contamination in the subsurface. Small volumes of hydrocarbons or releases detected soon after release tend to be located near the source and can be remediated by direct removal. Large volumes or older releases may lead to more extensive subsurface contamination. The extent of contamination is also controlled by the potential pathways of migration. For example, free product or dissolved hydrocarbons may move rapidly through coarse-grained subsurface materials or in utility beddings. If the contamination extends to points where groundwater is used or discharged to surface water, then the risk of potential exposure is present. The hydrocarbon vapors can pose an explosive risk or health risk where high vapor concentrations migrate to residences, buildings, or accessible subsurface utilities.

Hydrocarbons released to the subsurface partition into one or more of four phases:

- Vapor - Gaseous state; occurs primarily in the unsaturated zone.

- Residual - Adsorbed to soil particles and trapped within soil pores; occurs above or below the water table.

- **!** Aqueous - Dissolved in groundwater and soil moisture.
- **!** Liquid - Free product; held up by buoyancy at the water table and capillary fringe, or perched above low permeability lenses in the unsaturated zone.

If a sufficient volume of petroleum hydrocarbons is released into the subsurface, then all four phases are generally present. As each of these phases behaves differently, remediation will typically require a combination of corrective action technologies. Recovery of free product is an especially important aspect of site remediation because improper recovery techniques can cause reduced effectiveness and transfer significant portions of the contaminant mass into other phases.

Vapor phase hydrocarbons are found mixed with air and water vapor in the unsaturated zone. This phase tends to be the most mobile phase and can present an immediate threat from explosion or asphyxiation when the vapors migrate into confined spaces such as basements and sewers. Because of the mobility of hydrocarbon vapors, this phase can be effectively remediated using vacuum-air flow technologies. At any given time, the amount of vapor phase hydrocarbons at a site is typically a very small percentage of the total mass present.

Residual phase hydrocarbons typically do not extend great lateral distances from the source of the release, and they tend to be relatively non-mobile. Residual hydrocarbons can persist in the environment, and leaching of the more soluble components can continue to provide a source of groundwater contaminants for a long period of time. As a result of fluctuations in water table elevations, residual phase hydrocarbons can occur either above or below the water table. This effect, known as "smearing", can result in the immobilization of significant quantities of previously mobile free product. Above the water table, this phase often can be effectively remediated in situ by promoting volatilization and stimulation of natural biological processes. Residual hydrocarbons can occupy more than 50 percent of the total pore space in subgranular sediments. Generally, greater amounts of residual phase hydrocarbons are retained below the water table than above the water table.

Aqueous or dissolved phase hydrocarbons are found in soil moisture above the capillary fringe, in groundwater in the capillary fringe, and below the water table. Despite the relative insolubility of many constituents of hydrocarbon fuels, some constituents (*e.g.*, MTBE) are extremely soluble and can migrate dissolved in groundwater a significant distance from a site. Although dissolved hydrocarbons typically account for a very small percentage of the total mass of hydrocarbons released, they represent the largest volume of contamination and are spread over the largest area. They also represent the most probable pathway for human and environmental exposure.

Liquid phase hydrocarbons (free product or free phase) are characterized by having sufficient volume to saturate the geologic media such that the liquid hydrocarbons accumulate on the water table and readily flow into wells or excavations. Because it is the sufficiency of volume and not physical or chemical differences that differentiate between the liquid phase and residual phase, these two phases are often referred to as a single phase (*e.g.*, LNAPL). Both free phase and residual phase hydrocarbons can contribute to the contaminant mass in the vapor (gas) phase through evaporation and the aqueous phase through dissolution. Sorption onto soil particles contributes the residual phase. The liquid phase hydrocarbons may also constitute a threat to health and safety.

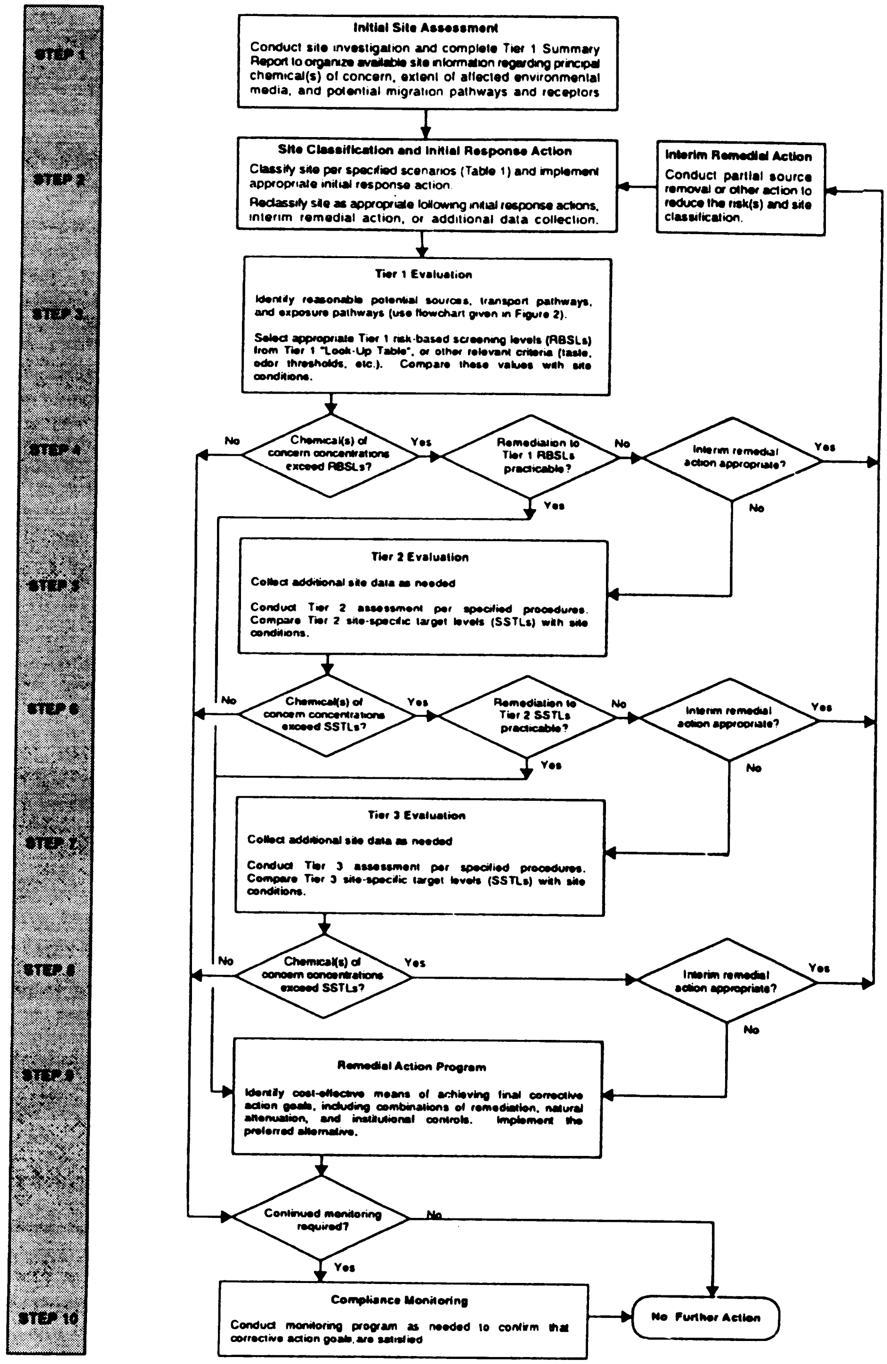
Risk-Based Corrective Action

Confirmation of a release from an UST initiates the corrective action process. The objective of the corrective action process is to assess site conditions and to implement a cost-effective response to protect human health and the environment. Traditional approaches have applied uniform procedures and standards to sites where the subsurface contamination varies greatly in terms of complexity, physical and chemical characteristics, and potential risk. Alternatively, and often more cost effectively, the procedures and remedial objectives can be developed based on a site-specific analysis of risk.

U.S. EPA encourages the use of risk-based decision-making in UST corrective action programs (EPA, 1995; OSWER Directive 9610.17). The American Society for Testing and Materials (ASTM) has issued a "Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites" (ASTM, 1995). The ASTM risk-based corrective action (RBCA; pronounced "Rebecca") process provides a framework for a consistent decision-making process for the assessment and response to a petroleum release. States generally modify this approach so it is tailored to their individual state needs. The RBCA process uses a tiered approach where corrective action activities are tailored to site-specific conditions and risks. Fundamental to the proper application of this approach is an adequate site assessment. The entire procedure is comprised of ten steps (Exhibit II-1). Free product recovery is typically conducted during steps 2 and 9. Consequently, state and local regulators may need to review free

Exhibit II-1

ASTM Risk-Based Corrective Action (RBCA) Process Flowchart



Source: Reprinted, with permission, from the Annual Book of ASTM Standards, copyright American Society of testing materials, 100 Barr Harbor Drive, West Conshohoken, PA, 19428.

product recovery systems not only as specified in the Corrective Action Plan (CAP) but also in interim actions that may involve free product recovery. States that are adapting the ASTM standard or developing state-specific risk-based procedures need to determine how to review free product recovery plans so that the steps (of the plan) are well integrated into the rest of their program. For more information, please refer to the ASTM standard E 1739-95.

Steps In Reviewing Free Product Recovery Plans

Following are the steps that the state regulator should take when reviewing free product plans (see Exhibit II-2):

- Determine if site data are sufficient to evaluate the need for free product recovery and/or recovery design.
- Determine if proposed free product approach is consistent with comprehensive CAP and if remedial action objectives are clear.
- Determine if active free product recovery is necessary.
- Evaluate design of the free product recovery system.
- Evaluate operations and monitoring plan.

A checklist based on these steps is presented at the end of the manual.

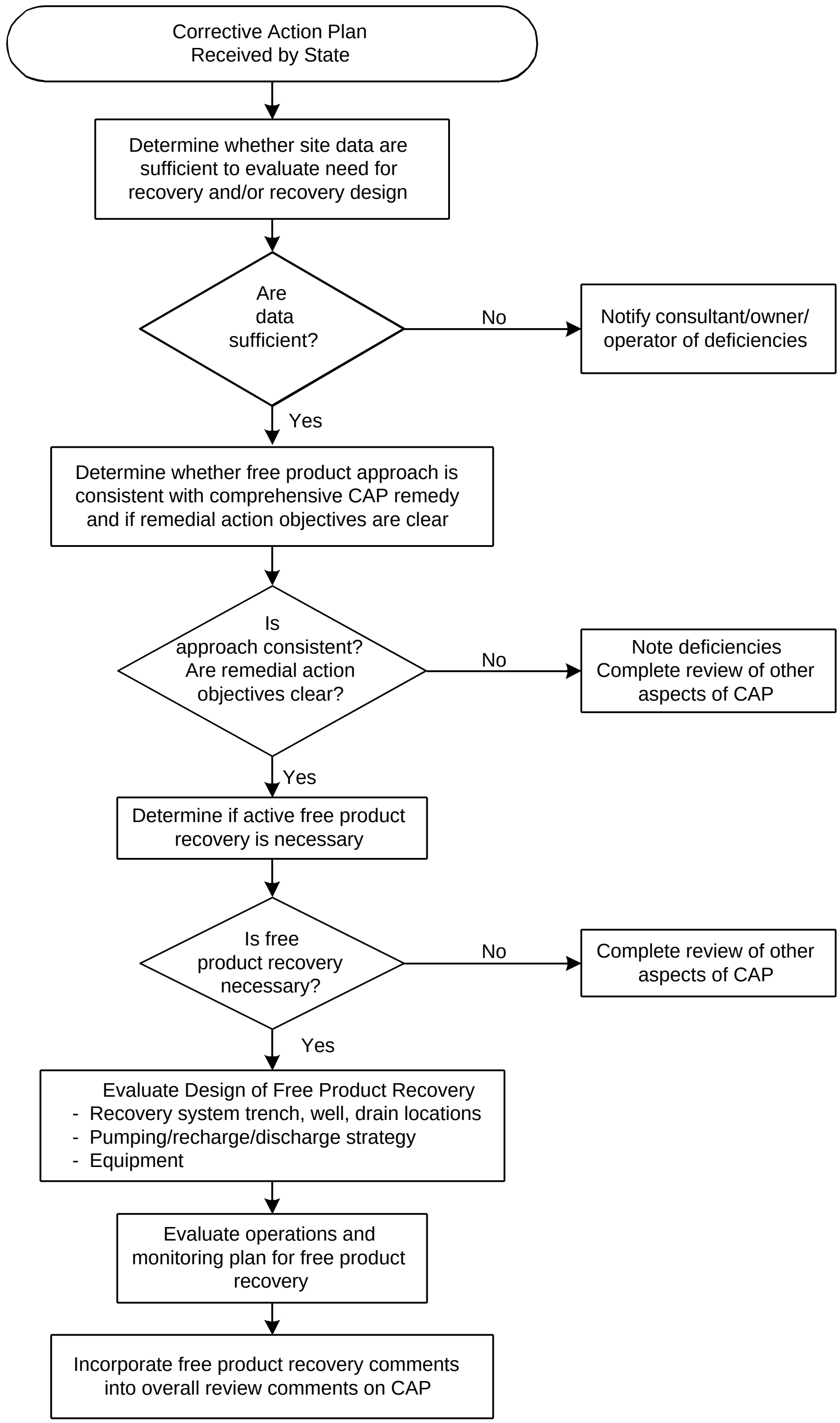
Step 1. Review Data Adequacy

The site information and data that are contained in the free product recovery plan or CAP must provide an adequate basis for making decisions regarding the corrective action.   Information required for a CAP is generally more extensive than that required for a free product recovery plan. The need to implement a free product recovery system is typically determined on the basis of site data that indicate that free product is present and recoverable. For a CAP, the need and type of corrective action are based on an evaluation of risks to human health and the environment. The CAP must also consider hydrocarbons present in the vapor phase or dissolved in the liquid phase.

The technical data necessary to evaluate a free product recovery plan include:

Exhibit II-2

Major Steps in Reviewing Free Product Recovery Plans



- Description of site.
- Description of current and past operations relevant to USTs and piping.
- Information on past releases or spills.
- Summary of current and completed corrective actions and investigations.
- Description of regional and site hydrogeological conditions.
- Discussion of hydrocarbon phase distribution in the subsurface.
- Listing of the physical and chemical properties of liquid hydrocarbon phase.
- Estimates of free product extent (maps and cross sections), free product volumes, and recoverability.

The significance of this information and methods for obtaining it are discussed in Chapters IV and V.

Step 2. Evaluate Remedial Objectives Of The Site

A free product recovery system is often a small part of a comprehensive remedy that also addresses contamination dissolved in groundwater and/or vapors in the unsaturated zone. The remedies proposed for each medium must be compatible. For example, the pumping and treating of contaminated groundwater may result in large drawdowns of the water table. If large drawdowns occur in the vicinity of the free product, then the free product may be drawn to a lower depth where it may become immobilized (*i.e.*, the “smearing” effect) and contaminate previously clean aquifer materials. An example of compatible remedies is the combination of a soil vapor extraction system and free product recovery in moderately permeable soils. Operation of the soil vapor extraction system may actually enhance the effectiveness of a free product recovery system by helping to maintain a higher saturated thickness in the aquifer than would occur with free product recovery only.

Remedial objectives should be clear, achievable, and measurable. A remedial objective of removing all free product may be clear but not necessarily achievable. Many free product recovery systems have the capability to reduce the free product thickness to 0.01 foot or less, however, they may not be cost effective to implement at a site with accumulations on the order of 0.1 foot or less. Minimal amounts of free product will exist no matter how effective the free product recovery system. Therefore, the remedial objective should also include success measures such as maximum thickness of free product in wells (*e.g.*, less than 0.01 foot or reduction to no more than a sheen) or minimum recovery rates (*e.g.*, 2 gallons per month).

Step 3. Evaluate Need For Active Free Product Recovery

Active free product recovery may not be necessary (or feasible) unless free product is present in sufficient volumes which can be recovered effectively. The necessity for free product recovery should be determined based on an analysis of the feasibility of collecting significant amounts of free product. Feasibility depends not only on site conditions, but also on the chosen technology. For example, although free product is difficult to collect in fine-grained materials, the use of vacuum-enhanced recovery may increase the volume of free product that can be collected.

Factors which would suggest a need for free product recovery include:

- Estimates of free product at water table that are moderate to high (greater than 200 gallons).
- Permeable aquifer (*e.g.*, sands and gravels) or hydraulic conductivity greater than 10^{-3}cm/sec.
- Thick accumulations of free product in wells (greater than 1.0 foot).
- Nearby surface water or groundwater use (*i.e.*, close proximity to receptors).

Free product recovery is generally infeasible or otherwise unnecessary at sites where the following factors apply:

- Low volumes of free product (less than 50 gallons) at the water table.
- Distant (greater than 2,500 feet from free product plume) surface water discharge points and no nearby groundwater use.
- Very low permeability media (*e.g.*, silty clay and clay).

- Thin accumulations of free product in wells (less than 0.1 foot).

- Inclusion in the CAP of other remedial alternatives such as soil vapor extraction or pump-and-treat.

The need (or lack of need) for a free product recovery system may not be clear at all sites (*e.g.*, those with free product volume or free product thickness that fall between the above guidelines). However, as a general rule, where two or more favorable factors (with respect to free product recovery) apply to a given site, the need for free product recovery is indicated; conversely, where three or more unfavorable factors apply, free product recovery is generally not indicated.

Step 4. Evaluate Design Of Free Product Recovery System

It is also necessary to verify that the design of the free product recovery system is likely to be effective. The major design considerations include:

- Use of wells or trenches.

- Number and location of wells and or trenches.

- Fluid production rates, vacuum pressures, fluid elevations to be maintained in wells or trenches.

- Design of wells or trenches in terms of construction specifications and depth.

- Pumping, skimming, or vacuum equipment.

- Pipelines and manifolds.

- Instrumentation.

- Storage, separation, and treatment facilities (not covered in this guidance).

The rationale for the selection of the recovery approach (skimming, water level depression and collection, or dual phase extraction) should be checked for consistency with remedial objectives. For example, depressing the water table is used when one of the remedial objectives for free product recovery is to contain the free product plume.

The free product recovery plan may include the results of a capture analysis or computer modeling analysis to support the design of the network of wells or trenches and associated pumping rates, fluid elevations and/or vacuum pressures. Simple checks for small systems are suggested in Chapter IV. For complex sites with large volumes of free product, or where sophisticated models have been used in the free product recovery plan, the reviewer should probably seek guidance from an environmental professional with experience in computer modeling.

Step 5. Evaluate Operation, Maintenance, And Monitoring Approach

The free product recovery plan should include an Operation and Maintenance (O&M) plan that describes equipment operation and maintenance and monitoring activities at the site.

Monitoring parameters typically include:

- Fluid production rates at wells or drains (both free product and groundwater).
- Oil thickness in wells.
- Groundwater elevations in wells.

For dual phase recovery systems, vacuum pressures and air flow extraction rates at wells or on the manifold need to be monitored. The O&M plan should specify monitoring points and frequency for each monitoring parameter. The O&M plan should also describe monitoring activities to be continued once the free product recovery system has achieved its remedial objective(s) and associated criteria. The details of an O&M plan depend on site conditions and the free product recovery technology selected (see Chapter V for further discussion).

Primary References

ASTM, 1995. *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites*, E 1739-95, Annual Book of ASTM Standards, Philadelphia, Pennsylvania.

EPA, 1995. OSWER Directive 9610.17: Use of Risk-Based Decision-Making in UST Corrective Action Programs, Office of Underground Storage Tanks.